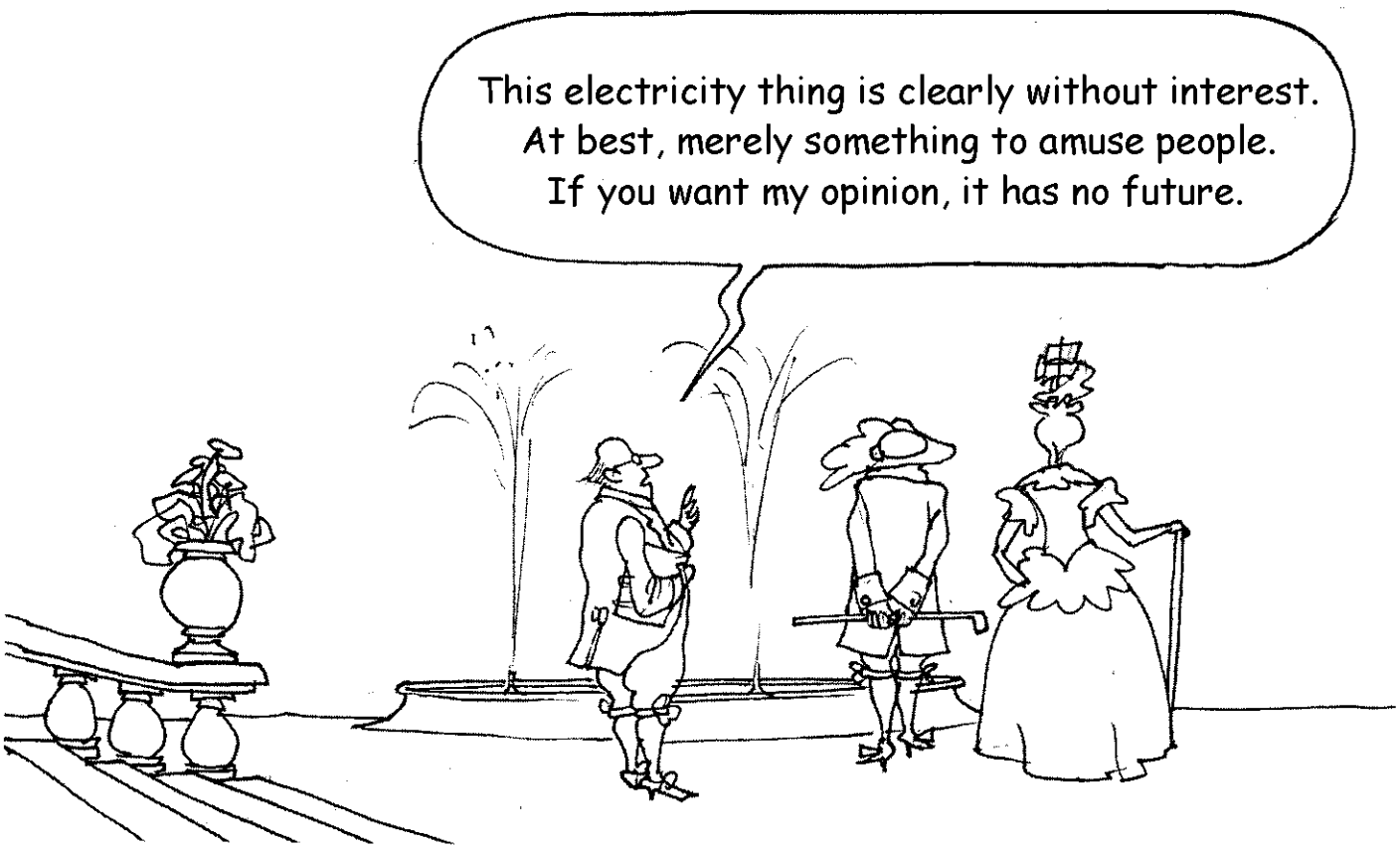
Jean-Pierre Petit

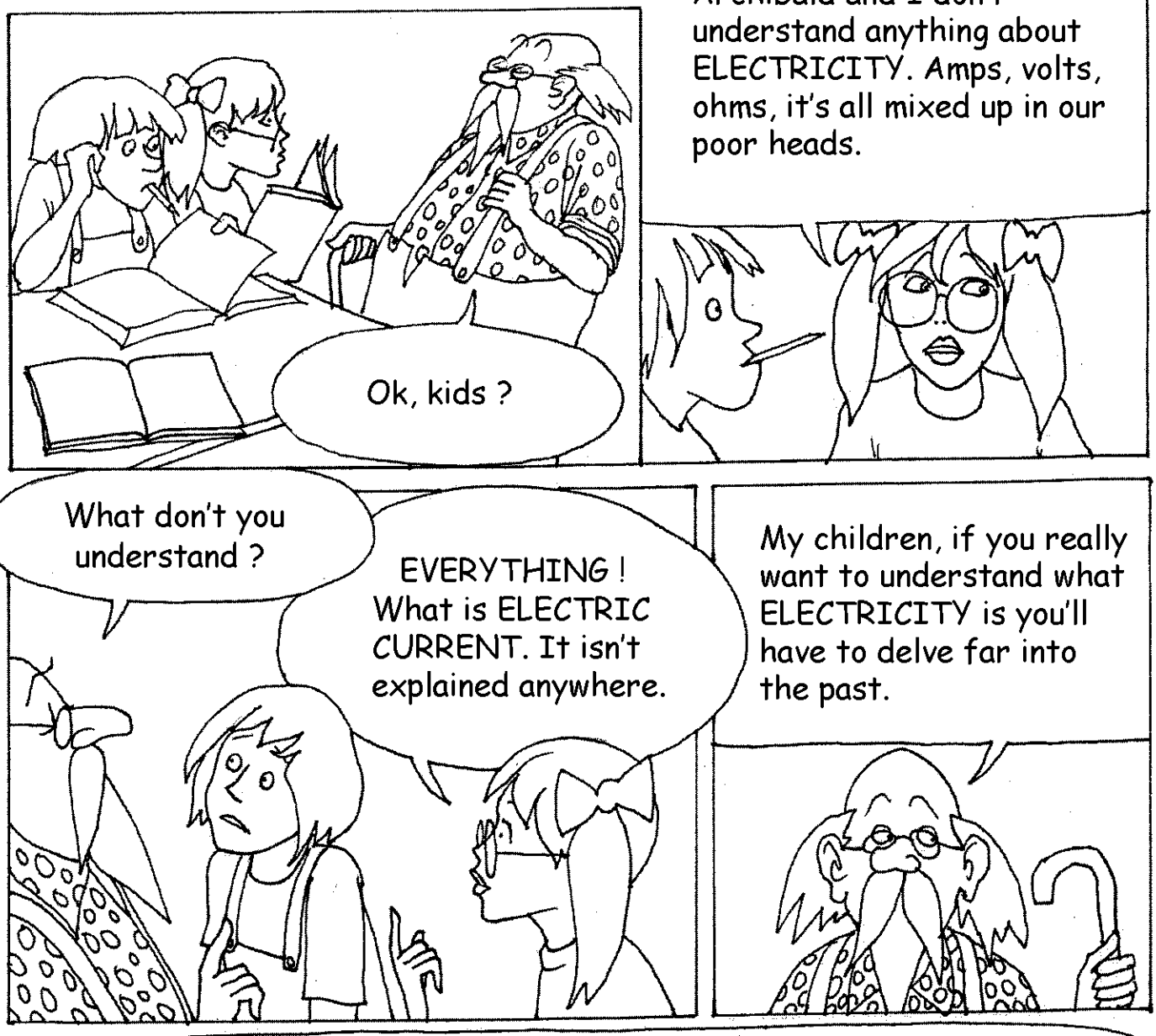
AMBER AND GLASS

A History of electricity



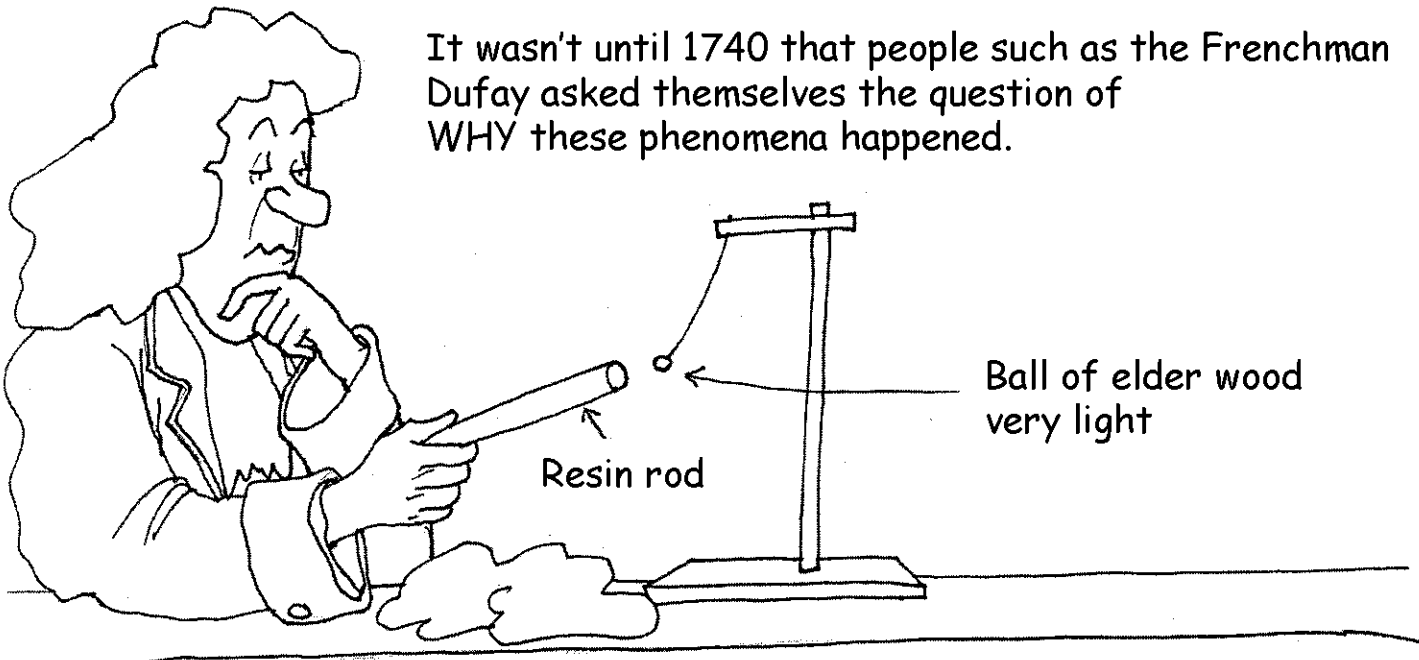
à Vladimir Golubev,
mon frère

PROLOGUE

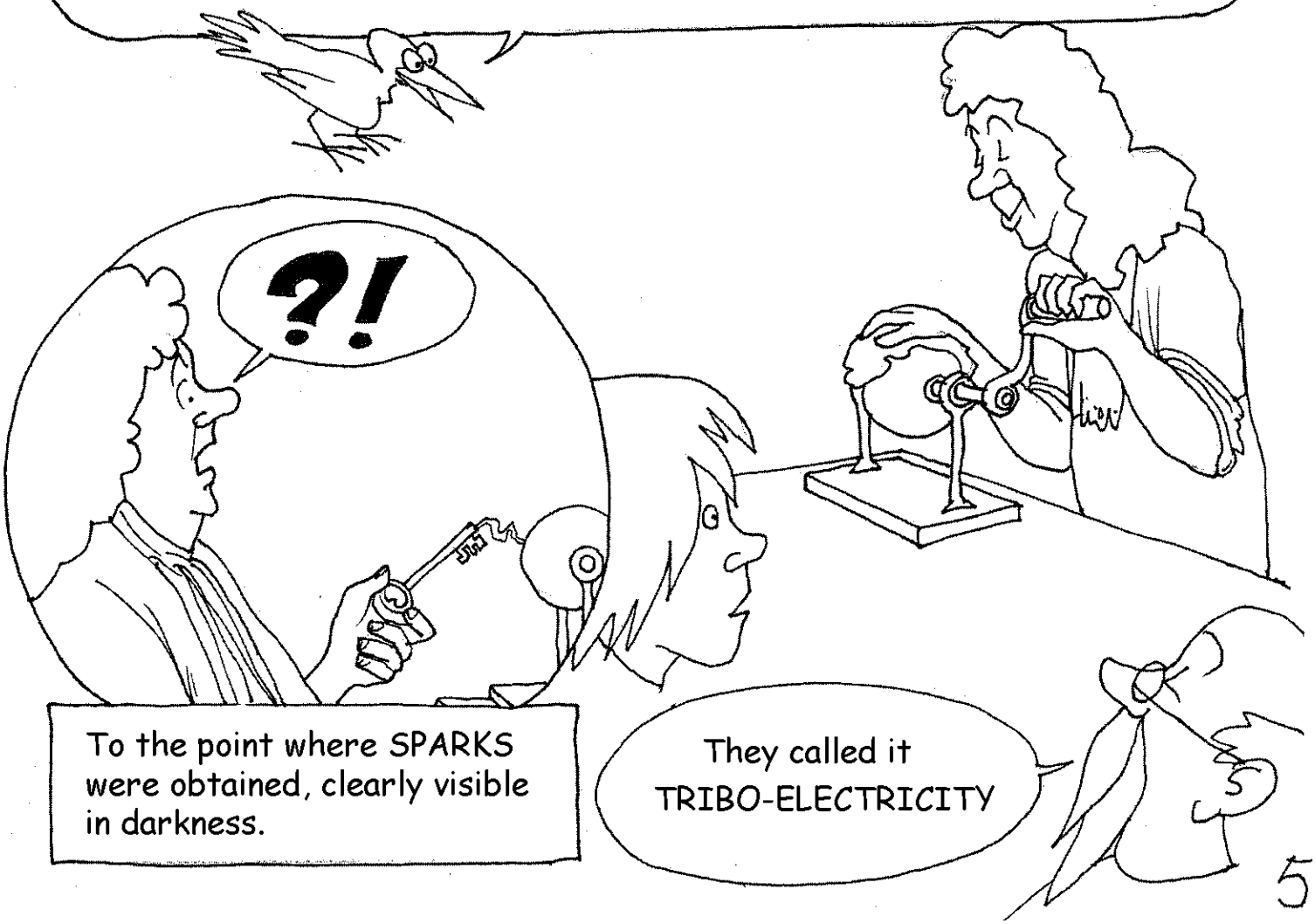

Ok, kids ?
Grandad, it's a catastrophe. Archibald and I don't understand anything about ELECTRICITY. Amps, volts, ohms, it's all mixed up in our poor heads.
What don't you understand ?
EVERYTHING ! What is ELECTRIC CURRENT. It isn't explained anywhere.
My children, if you really want to understand what ELECTRICITY is you'll have to delve far into the past.
Did you know that the word electricity comes from the Greek word ELEKTRON, which means amber. That's a fossil resin that can be found in the north of Europe in the shape of small yellow, translucid blocks that were used in ancient times to make jewellery.
During the 5th century B.C., the mathematician Thales noticed that when amber was rubbed with wool ...

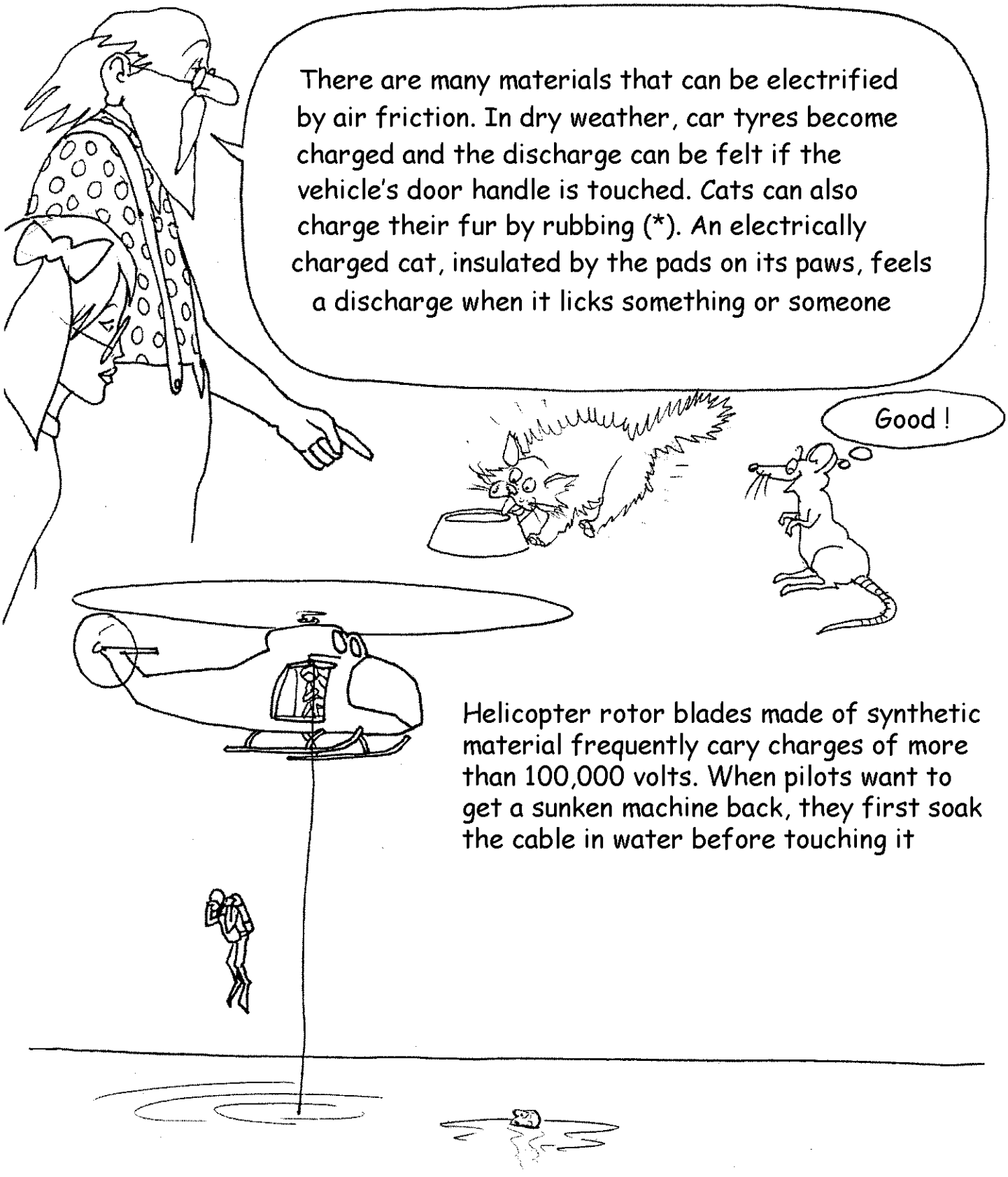
STATIC ELECTRICITY

It wasn't until 1740 that people such as the Frenchman Dufay asked themselves the question of WHY these phenomena happened.



People began to rub anything and everything to try. They noticed that not only could amber and resin be ELECTRIFIED BY RUBBING but that sulphur and GLASS ALSO HAD THIS PROPERTY. People then started to build machines with resin, sulphur and glass spheres and discs, which were electrified by rubbing them on small leather pads which were set in rotation via a crank.





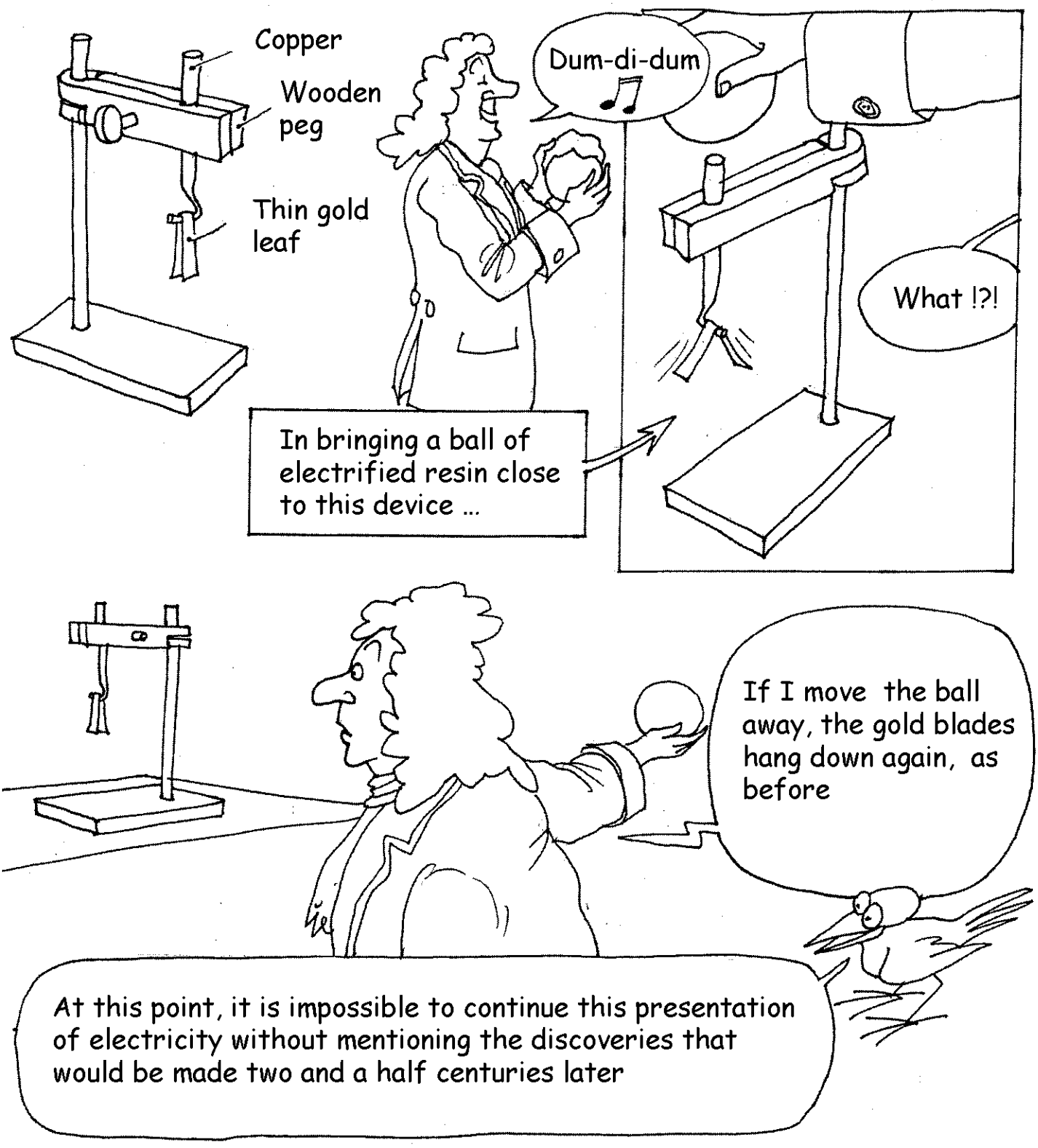
(*) Divers jump into the water from the helicopter to avoid becoming the link that will make the machine discharge in the sea water

A very furry cat can be charged up to 50,000 volts and produce very pretty sparks in darkness. But even if the tremor is felt, the damage to their bodies is insignificant because the electric intensity remains too weak.


A spectacular electric phenomenon can be seen by shutting yourself in a dark place with a reel of insulating tape. The operation is then done by pulling it off rapidly
By pulling it off ?
When the tape is pulled a bright blue light is observed at the spot where the tape comes unstuck
It's bright enough to allow a text to be read.
But that would be a very uneconomical way to light the room
Only certain materials can be electrified by friction. One could rub all available METALS without getting the least result

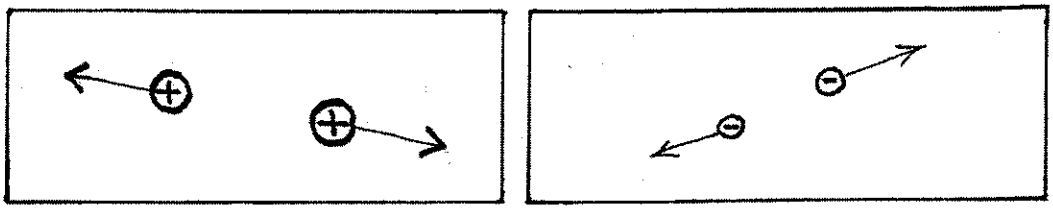
INDUCED ELECTRIFICATION

But it was discovered that this wasn't without effect when an electrically charged object, made of resin or glass, was brought near the metal



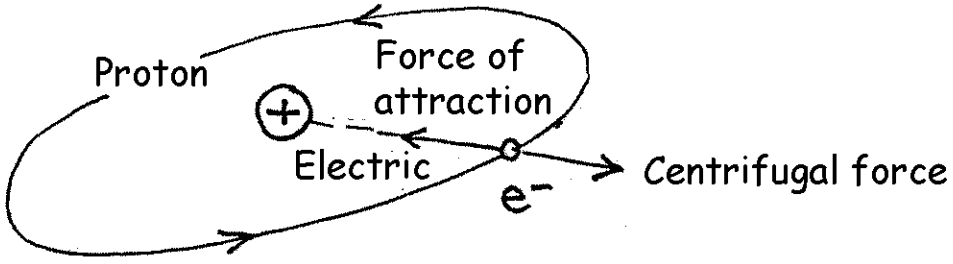
It wasn't until 1905 that the New Zealander Ernest Rutherford showed that matter was made of atoms. Then the Dane Niels Bohr described them as being made up of a positively charged NUCLEUS around which orbited one or several negatively charged ELECTRONS

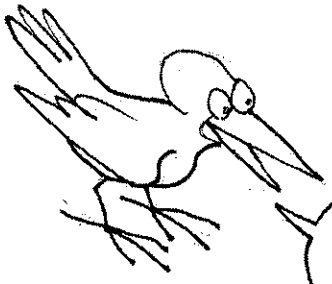
Charges with the same sign repulse each other



Opposite signs attract, which allows the creation of a HYDROGEN ATOM where one electron orbits around a nucleus made up of a unique PROTON, the force of electric attraction (between oppositely charged signs) balances out the CENTRIFUGAL FORCE

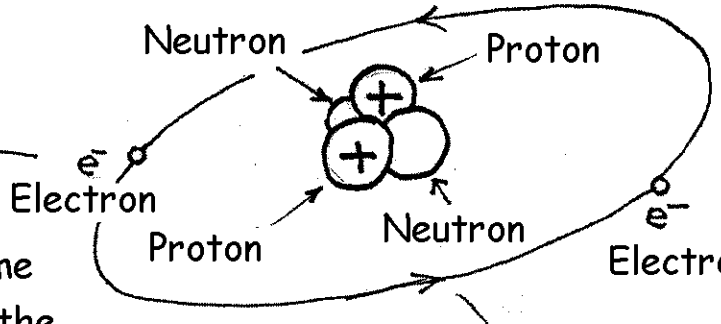
HYDROGEN ATOM





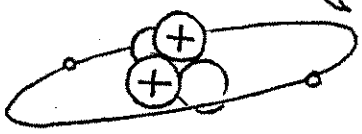
Several protons cohabit in the nuclei of other atoms, as well as electrically neutral particles called NEUTRONS

HELIUM ATOM

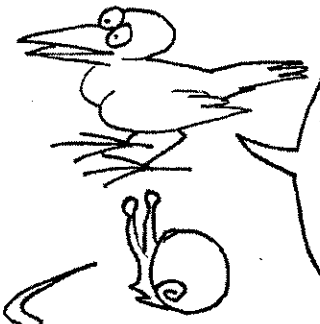


I don't understand. Particles with same sign repulse each other. What holds the two protons together in the nucleus of a helium atom ?

Particles making up the NUCLEI of atoms are called NUCLEONS. Their cohesion is ensured by the attractive NUCLEAR FORCE which, at a short distance, becomes greater than the force created by the electric charges.



Helium nucleus
2 protons
2 neutrons



In the nucleus of an atom there are always, more or less, as many protons, positively charged, as there are neutrons, which have no electric charge.

But there are ALWAYS as many protons, + charges, as electrons, with - charges, so making all atoms ELECTRICALLY NEUTRAL.

But there are ALWAYS as many protons, + charges, as electrons, with - charges, so making all atoms ELECTRICALLY NEUTRAL.

Example, the oxygen molecule : O_2

2 oxygen

or carbon dioxide atoms: CO_2

Oxygen Oxygen

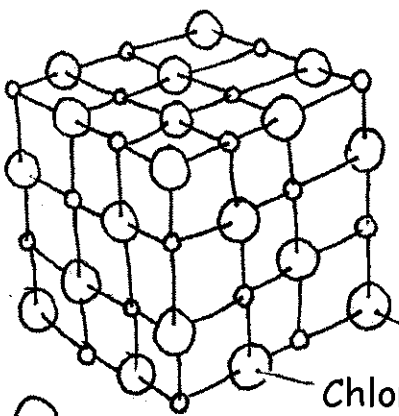
Carbon

or water :

Hydrogen Hydrogen

Oxygen

In LIQUIDS or GASES, molecules move freely while remaining electrically NEUTRAL. In a SOLID, nuclei are fixed in relation to each other. In a METAL, some of the electrons move freely between the fixed nuclei.



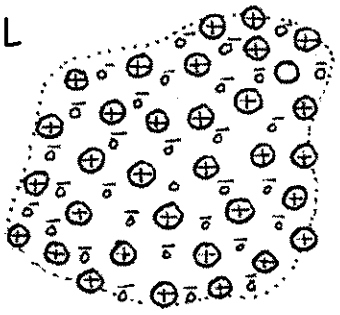
Cooking salt
Sodium chloride where the nuclei are arranged in a cubic network

Sodium

Chlorine

In a METAL (in a solid state) atoms are fixed in relation to each other. Some of the electrons move freely, like bees moving around in a hive. When a piece of metal is left alone, the density of the positive charges, contained in the nuclei, and the density of the negative charges, those of electrons, are equal. The milieu is electrically neutral.

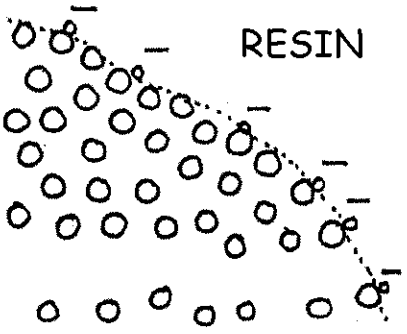
PIECE OF METAL

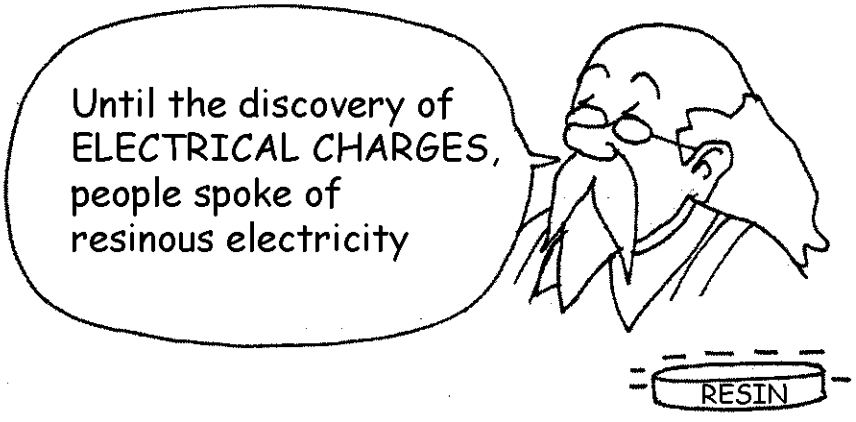


⊕ Nucleus

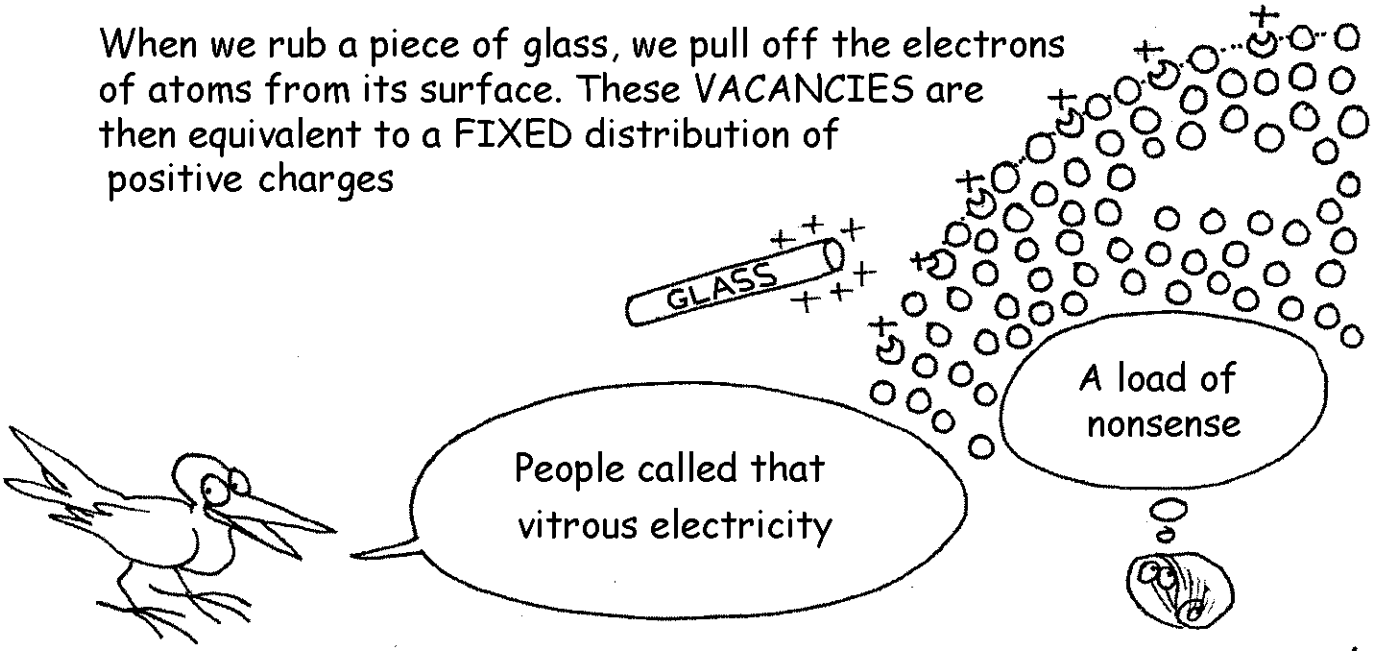
⁻ Electron

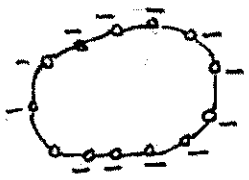
When we rub amber, or resin, its surface becomes covered with additional electrons which attach themselves to the atoms and create a FIXED distribution of negative charges

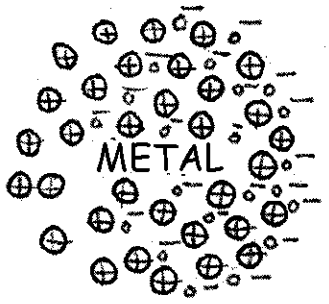




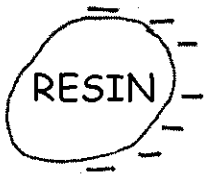
When we rub a piece of glass, we pull off the electrons of atoms from its surface. These VACANCIES are then equivalent to a FIXED distribution of positive charges

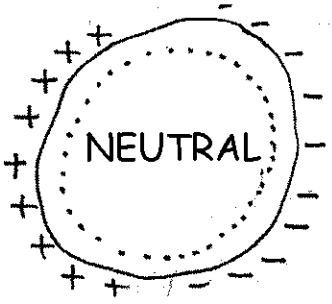






If we bring a piece of resin, negatively charged, towards a piece of metal, the latter's electrons are repulsed

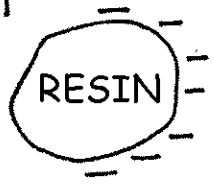


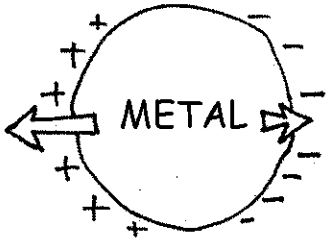


The induced electrification phenomenon is concentrated on the surface, the main body of the metal remains neutral. Under the effect of the negative charges carried by the resin block, everything happens as if the face opposite, of the metal block, becomes covered with positive charges, the part facing it being covered with negative charges

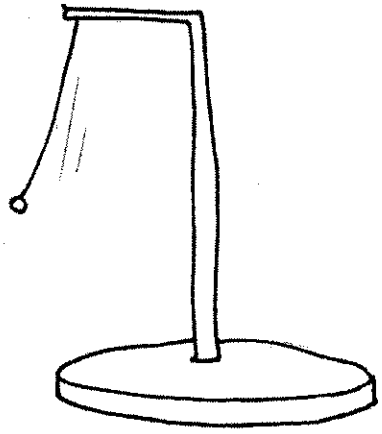
1 - Opposite charges are attracted to each other, charges with the same sign repulse each other

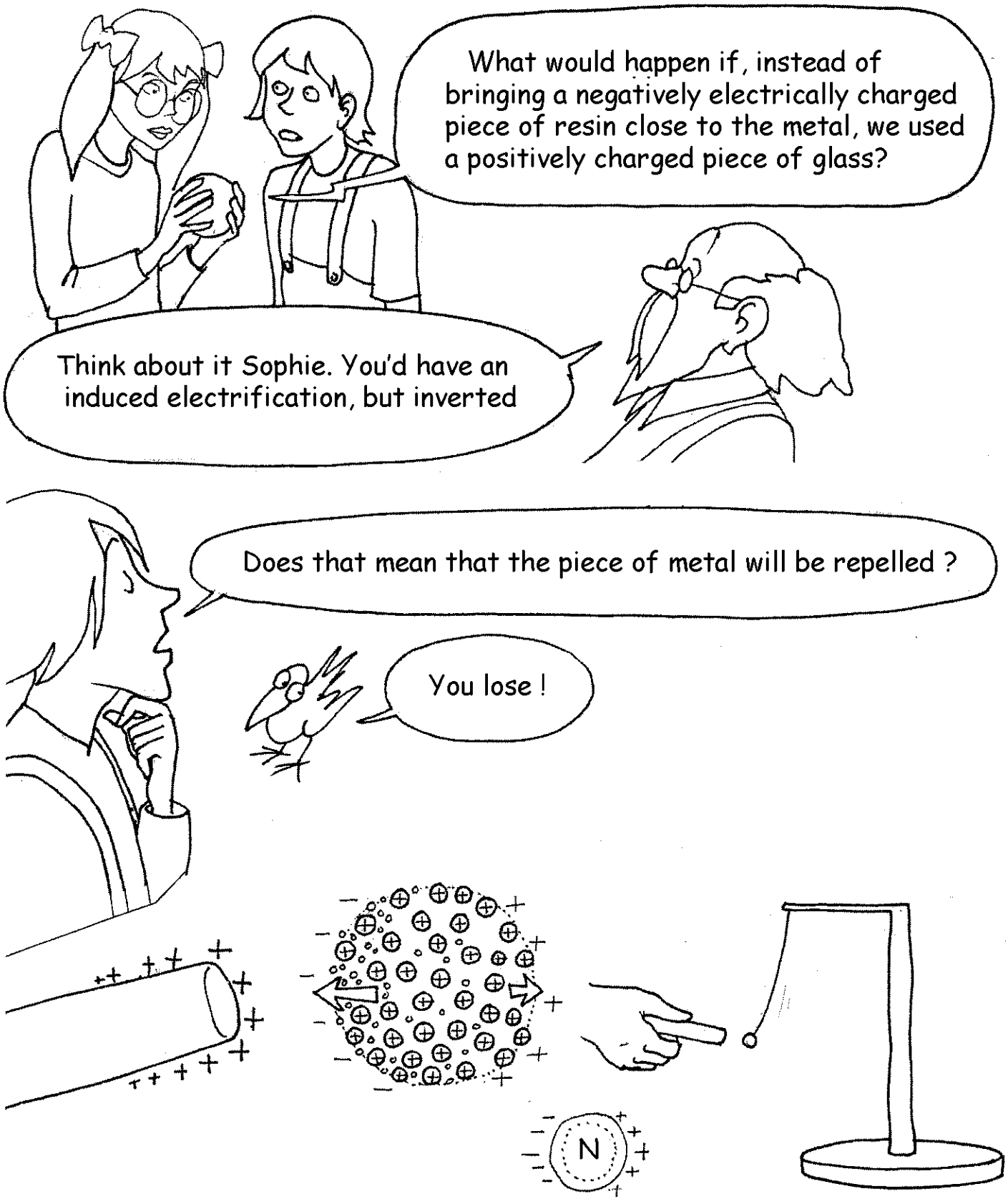
2 - These forces are proportional to the inverse of the square of the distance separating them



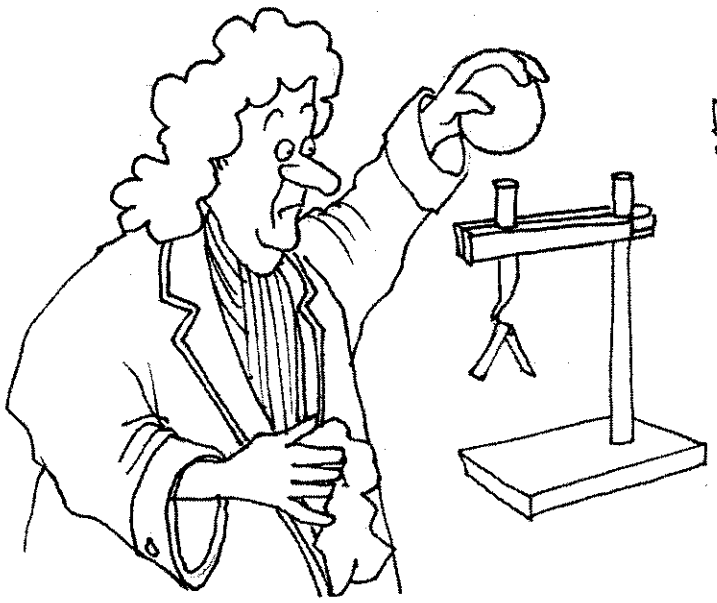


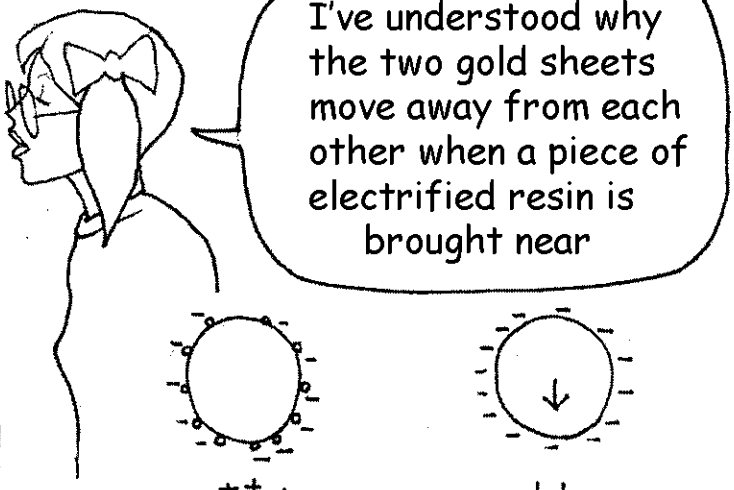
The + charges, being closer to the resin than the - charges, will exercise a slight attraction on the metal block



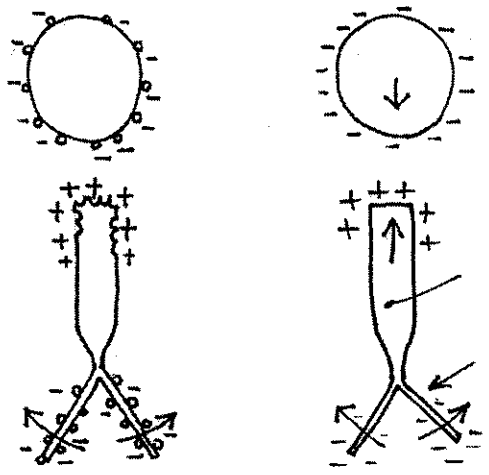


This time the glass block will attract the metal's electrons,
which will assemble on the side facing it and leave the opposite side.
The result will always be a (slight) attraction

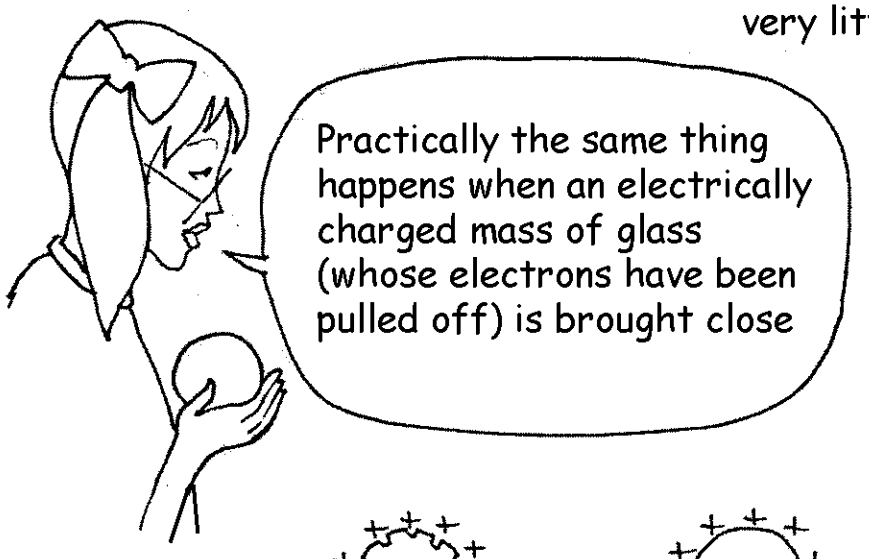


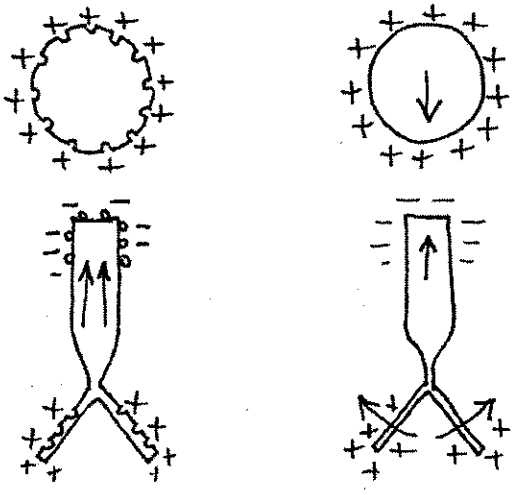


By the induced electrification effect, the charges present on the surface repulse the electrons of the metal towards the gold leaves. And as charges with the same sign repulse each other, the leaves move away from each other

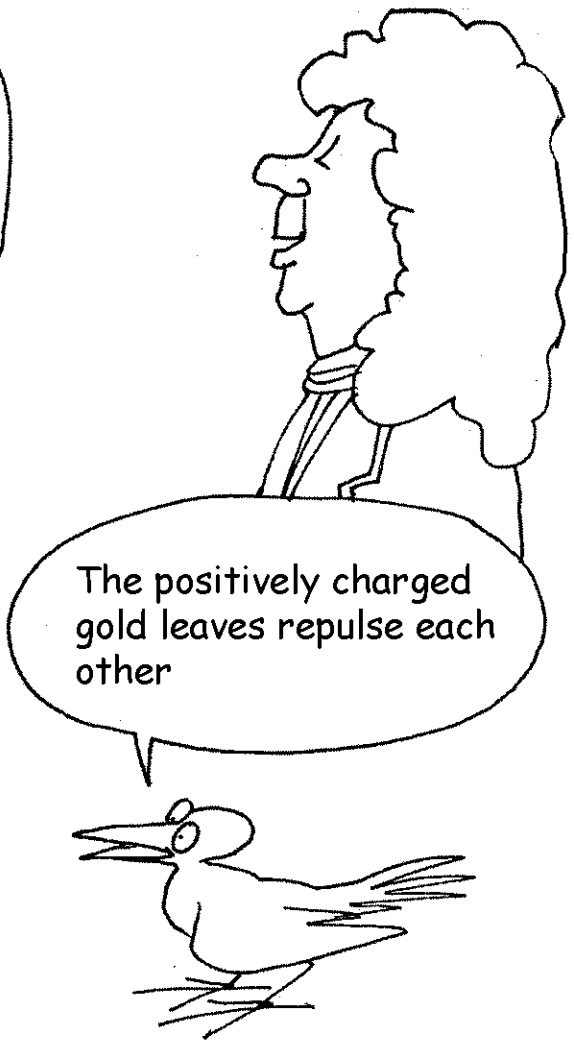


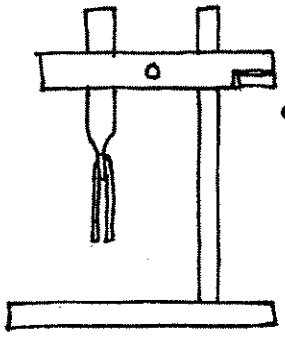
The two objects attract each other slightly. The gold leaves lift themselves up because they weigh very little.

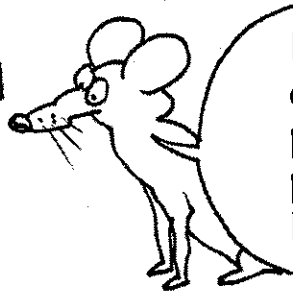




The electrons move off the gold leaves and collect on the upper part of the stick



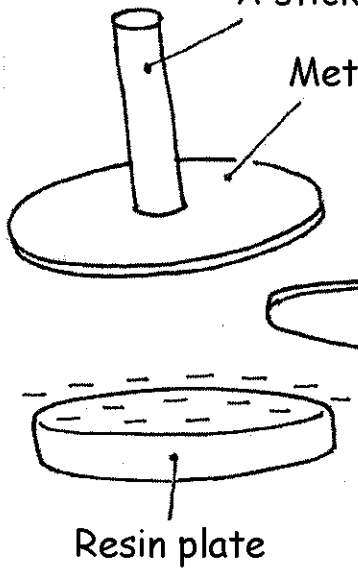




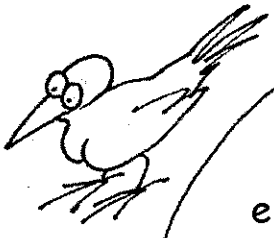
But when we move the electrified blocks away, the electrons return to their origianl place, the phenomenon disappears and the piece of metal becomes ELECTRICALLY NEUTRAL once more

How do you CHARGE a piece of metal ?

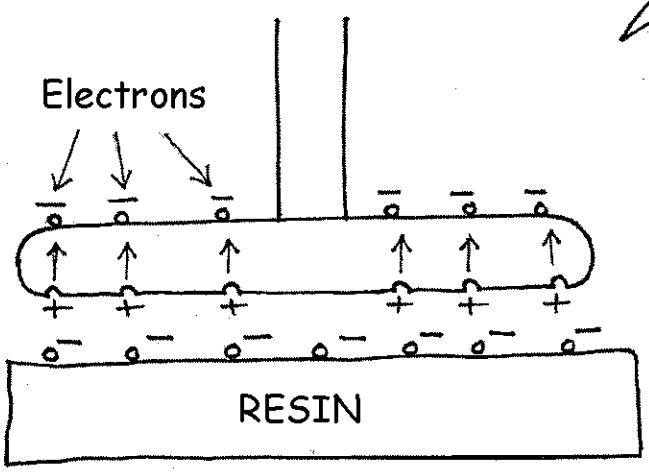
THE ELECTROPHORE

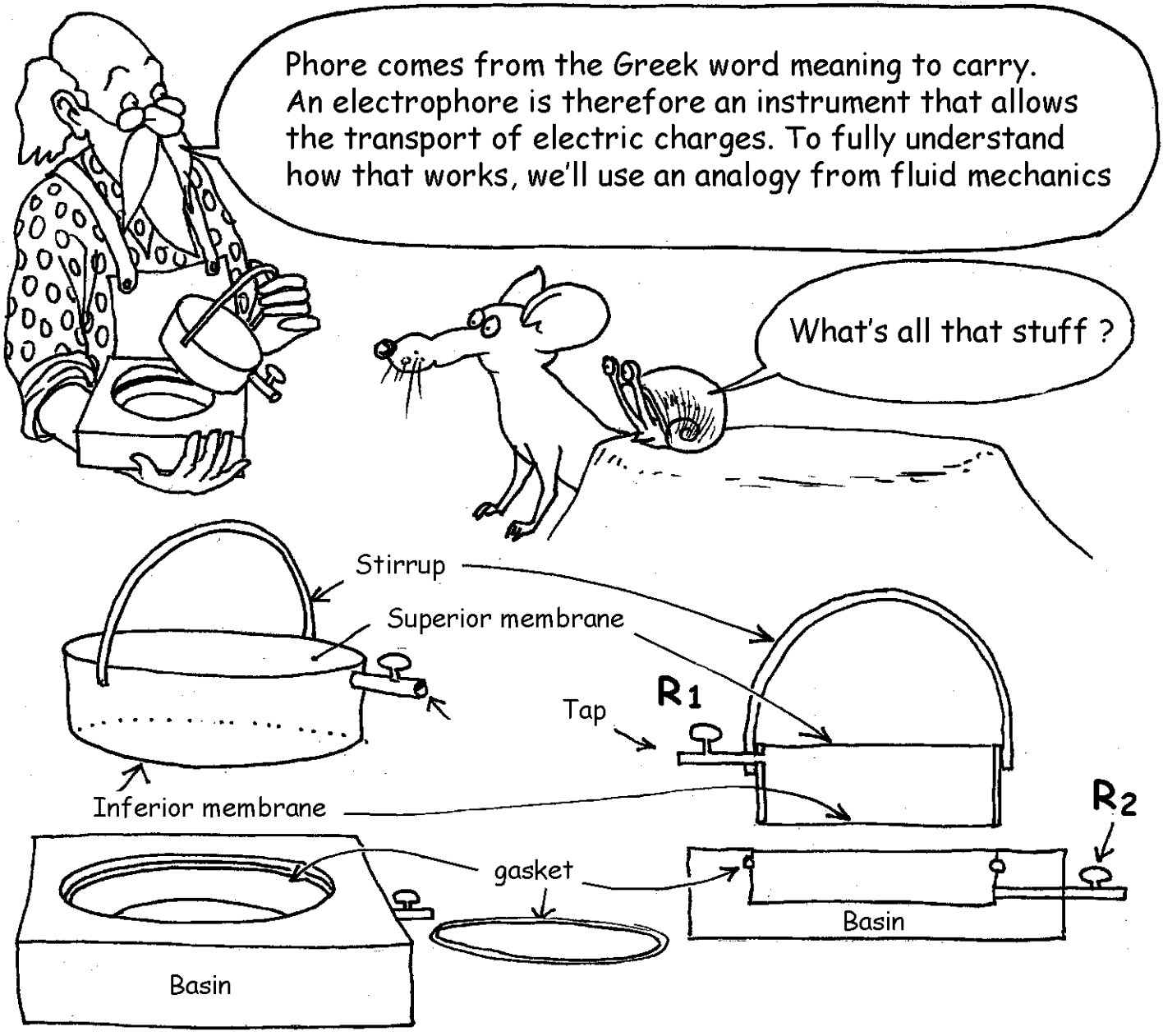


This very simple object was invented in 1800 by the Italian Volta. By bringing the metal disc close to an electrified resin disc, an effect of induced electrification occurs.

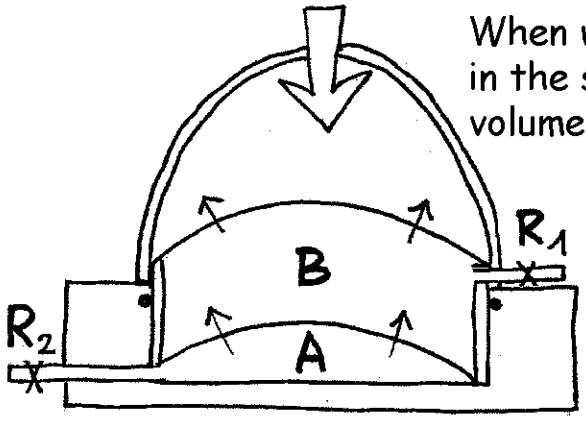


Repulsed by the electrons present on the surface of the resin disc, those of the metal leave the underside of the disc and migrate towards the superior part

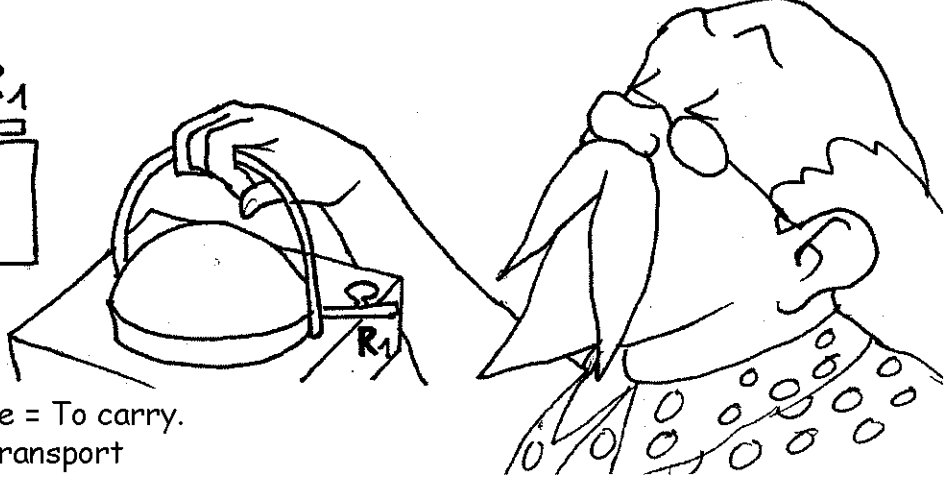




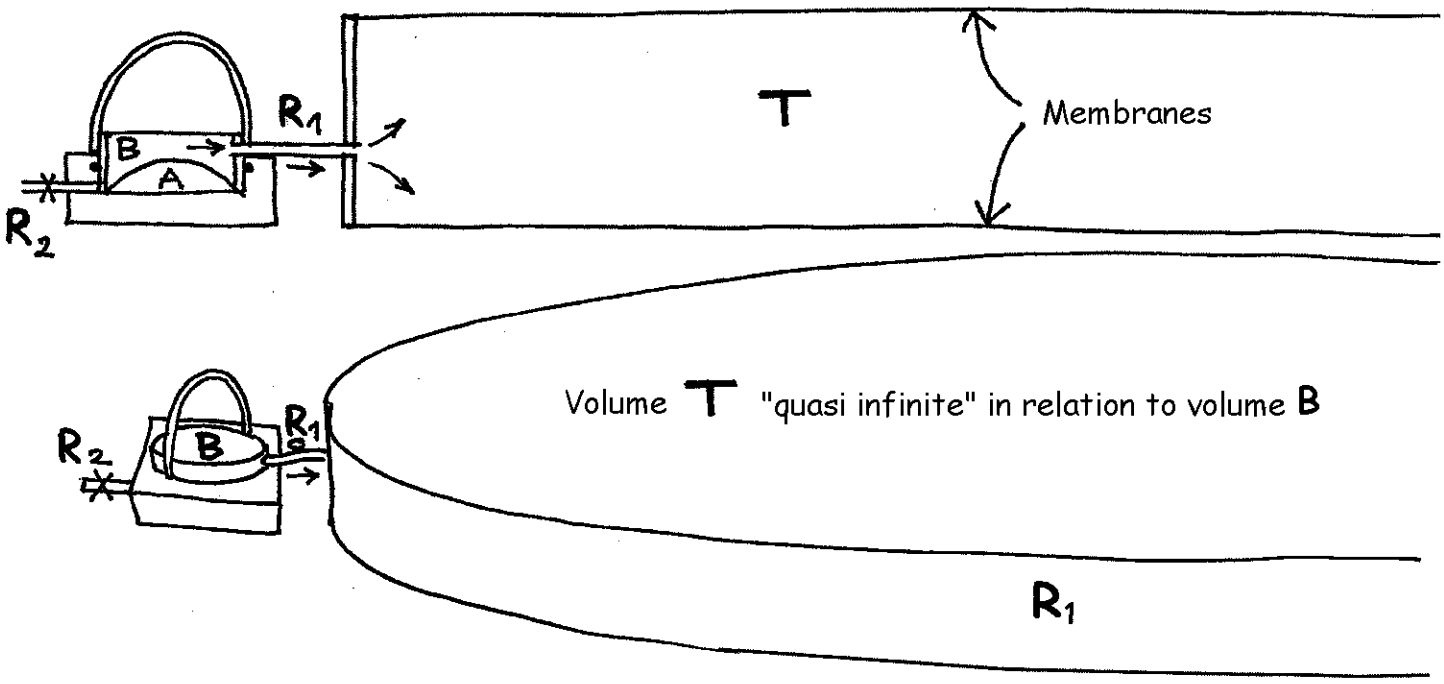
THE BAROPHORE (*)



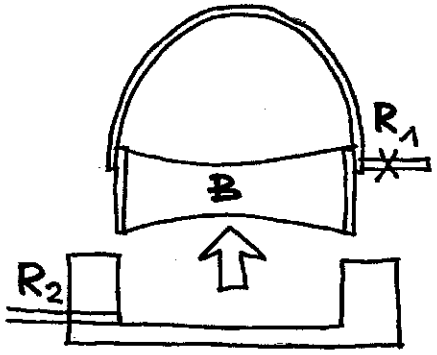
When we push the barophore into place, air is trapped in the space A. This overpressure is passed on into volume B and the two membranes curve upwards.



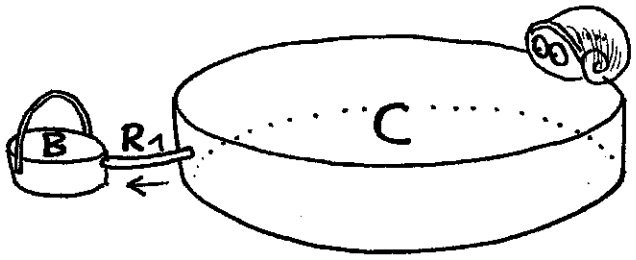
(*) Baros = pressure ; Phore = To carry.
Etymologically : pressure transport



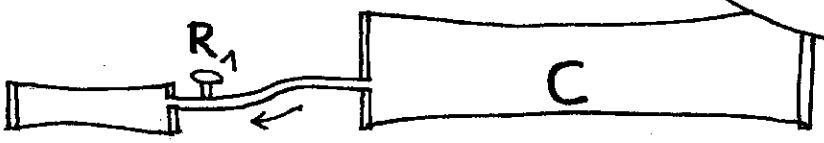
Next we connect volume **B** via the two membranes with an "immense" recipient **T**, also limited by two vast membranes. The volume is initially at atmospheric pressure. The pressures in **B** and **T** will cancel each other out, practically at atmospheric pressure. The upper membrane of the barophore will become almost flat. If we then close the tap R_1 and remove the barophore from its place, we obtain this :



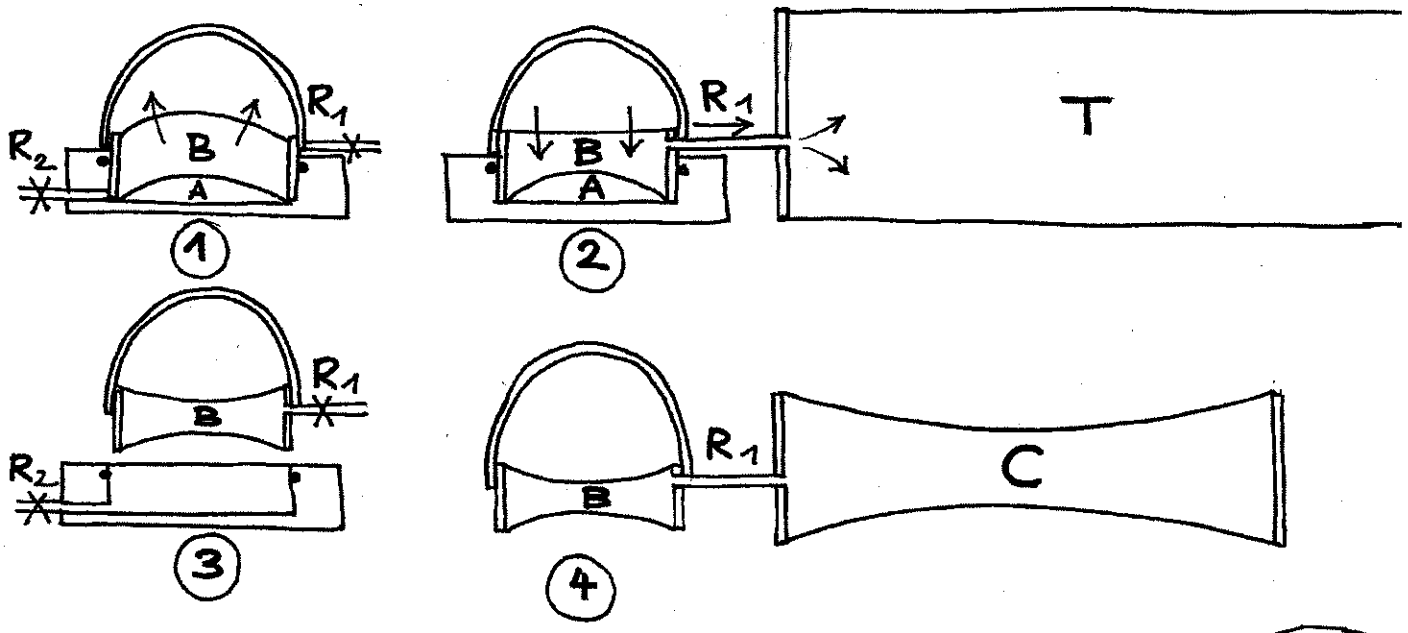
Volume **B** is then in **DEPRESSION** in relation to the ambient atmospheric pressure. We can transport this **DEPRESSED** air wherever we like, and use it to slightly reduce the pressure in a **CAPACITOR** of volume this time limit **C**



The two pressures equalise each other, the barophore **B** has thus allowed the creation of a slight depression in this **CAPACITOR C** filled with air, whose membranes hollow out slightly



We can repeat the operation and each time extract a little air from the CAPACITOR C, but less and less. However, after a certain number of operations, this will no longer work as the pressures (because of depressions) will have equalled out

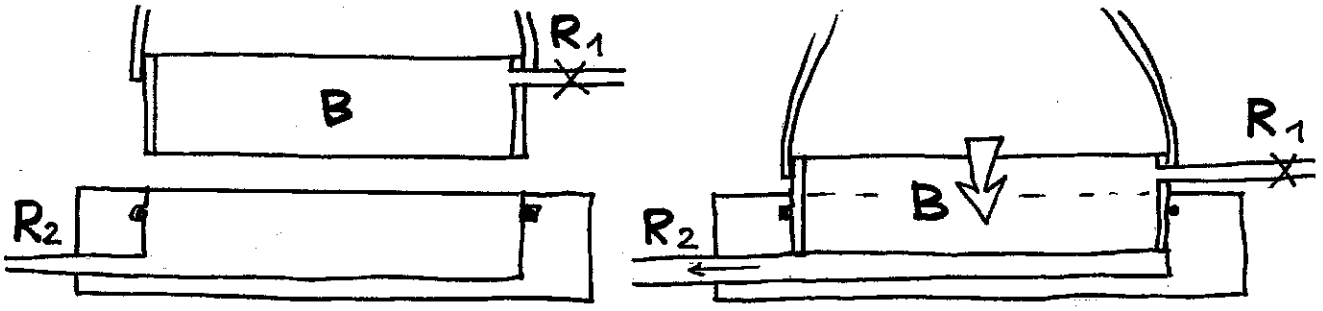


So we thus obtain a strange vacuum pump where, with the help of the barophore, we are **TRANSPORTING DEPRESSION**

Can we use it to transport overpressure ?

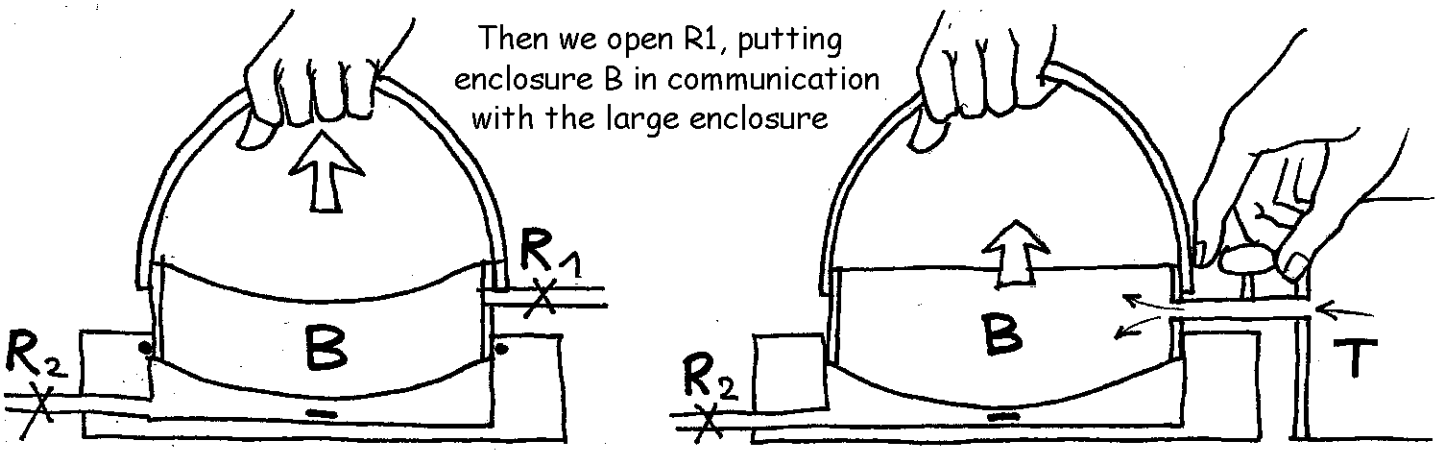
It's a right laugh this thing

When the barophore is at ambient pressure, no stress is exerted on the membranes. When we've finished the different manoeuvers we've created a DEPRESSION in enclosure B. STRESSES remain in the membranes. We qualify this STRESS as NEGATIVE. With the barophore we'll now put enclosure B, comprising the volume between the two membranes, into OVERPRESSURE and say that these are in a POSITIVE STRESS state



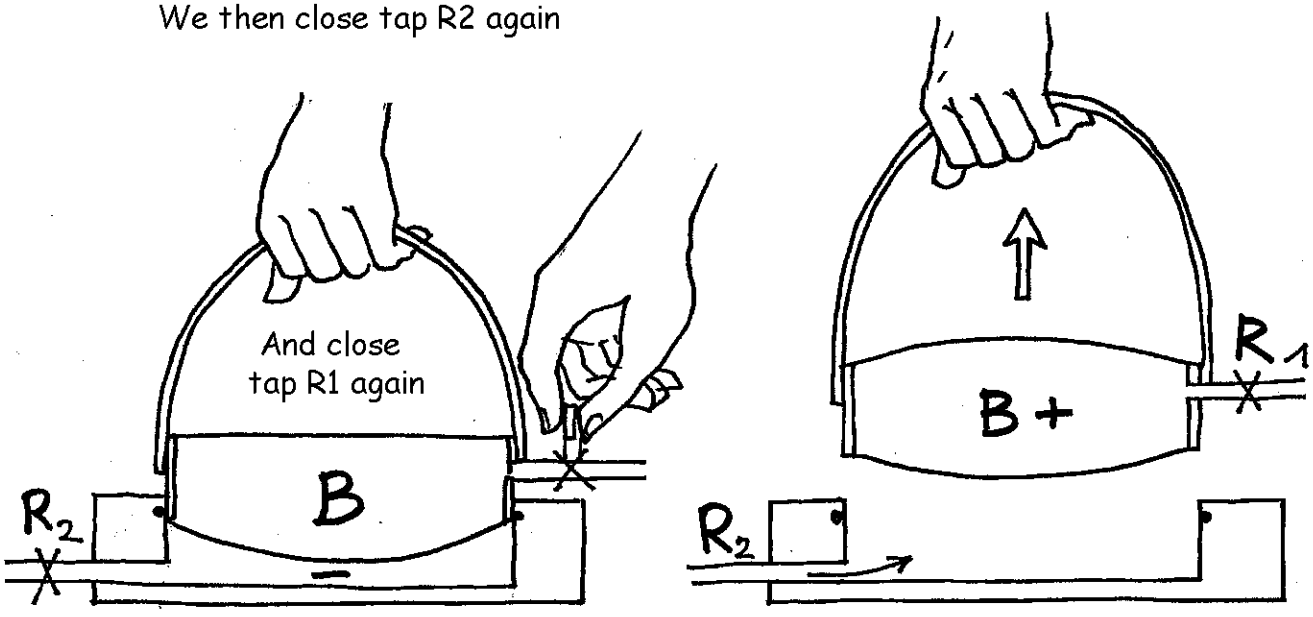
We open tap R2 and push the barophore into its housing

Then we open R1, putting enclosure B in communication with the large enclosure

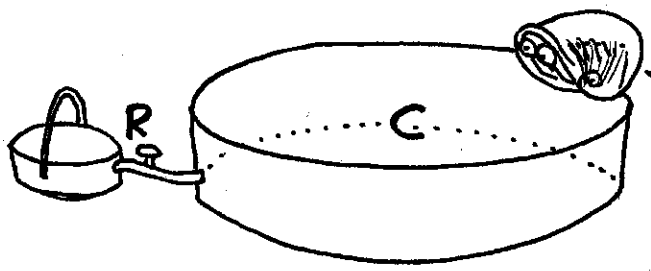


We then close tap R2 again

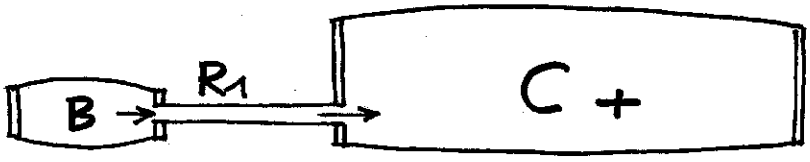
And close tap R1 again



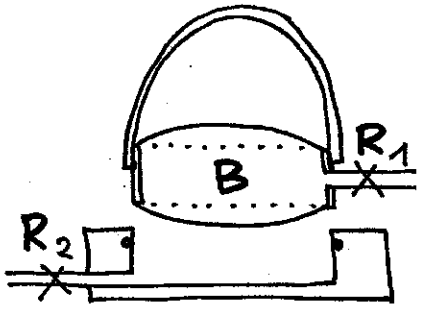
We open tap R2 and remove the barophore

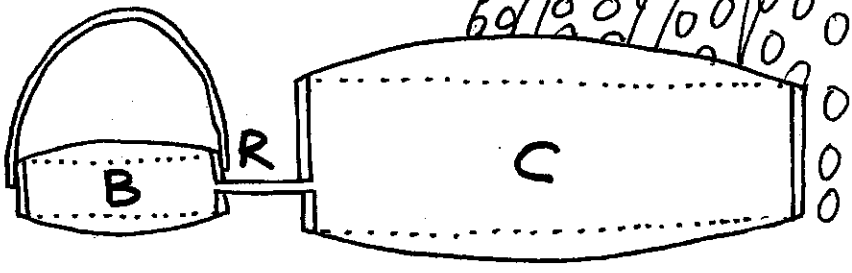


The two pressures equalise out, the barophore **B** thus allows the creation of a slight overpressure in the **CAPACITOR C** that is filled with air, so the membranes bulge slightly.

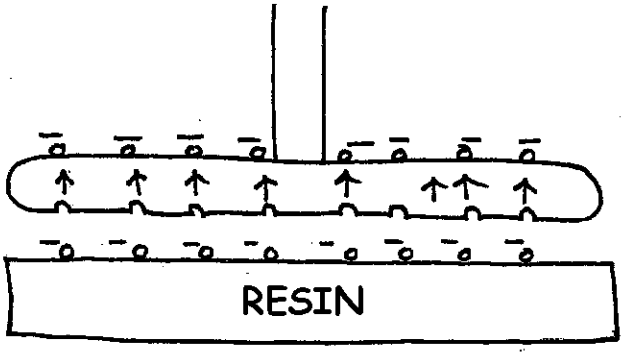


We can repeat the operation with this "hand compresser" until the pressures in **B** and **C** are equal. Then the pressure in **C** is at maximum. We could then say that **CAPACITOR C** has been brought to a maximum **POSITIVE STRESS**

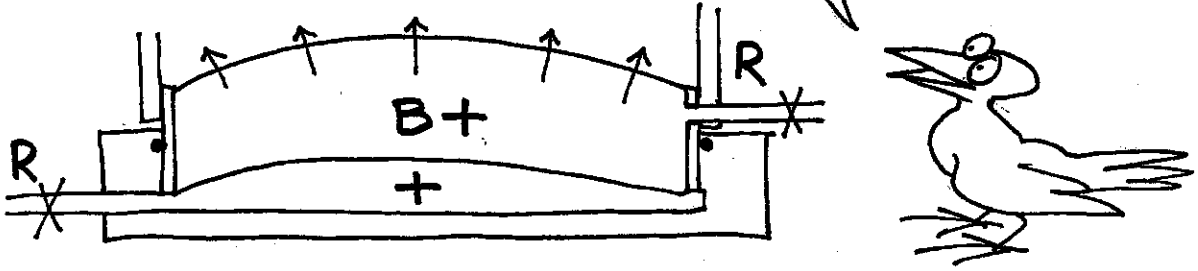


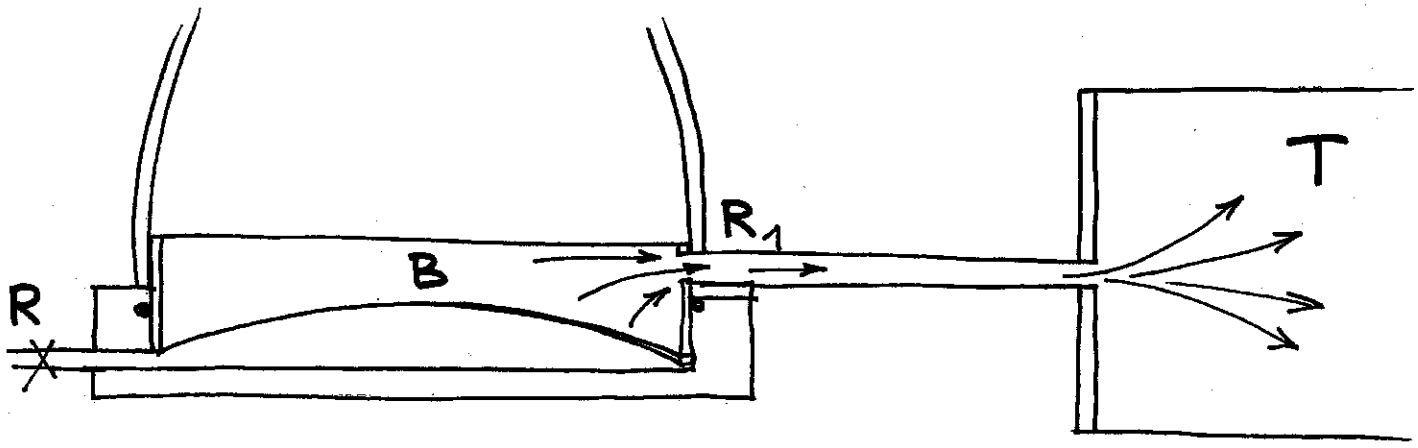


The "pump" becomes efficient when pressures **B** and **C** become equal, when the **STRESSES** in the membranes become equal.

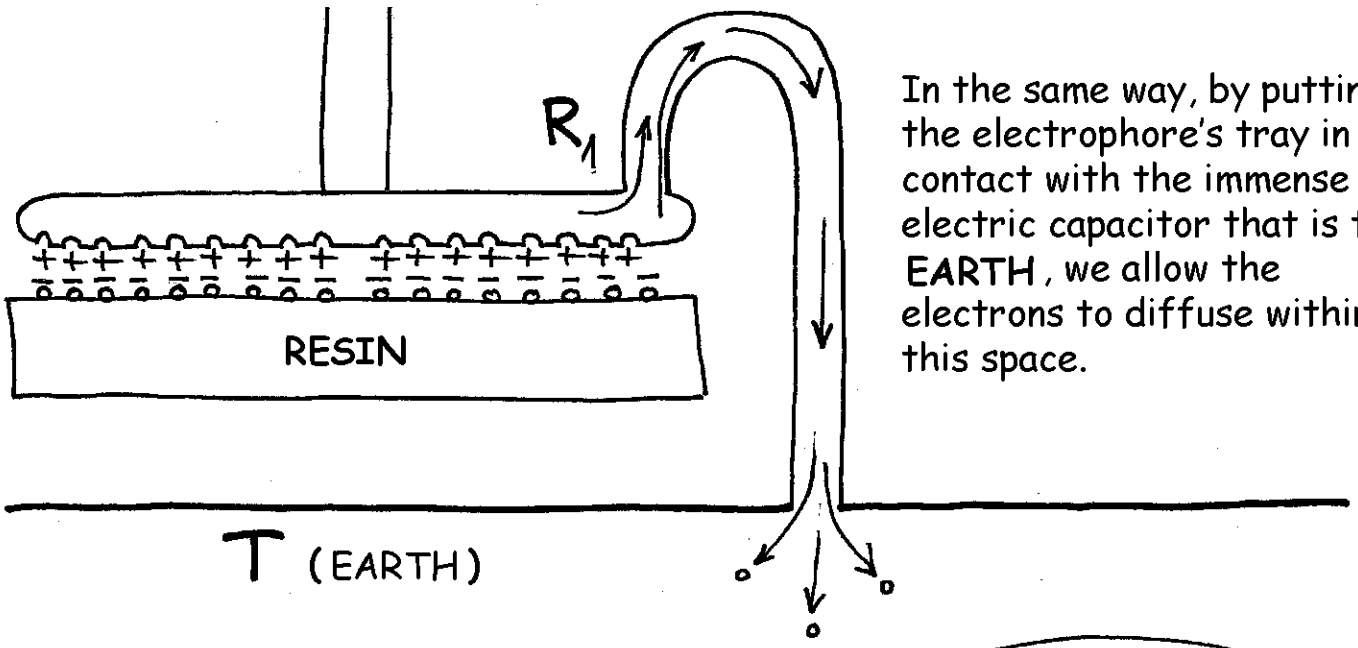


Let us return to our electrophore. The electrons present on the resin's surface repulse the metal's electrons toward the upper part of the disc.

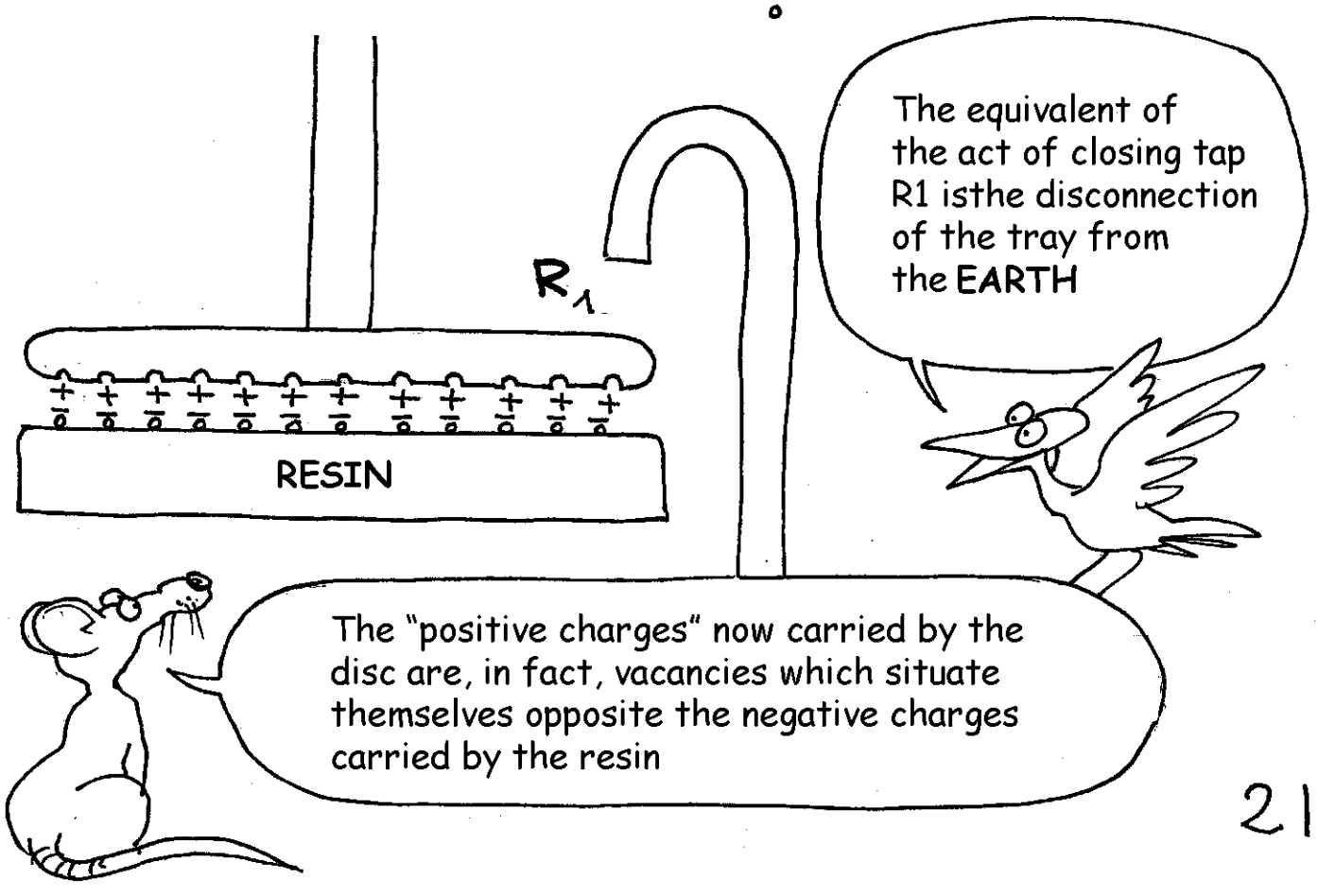




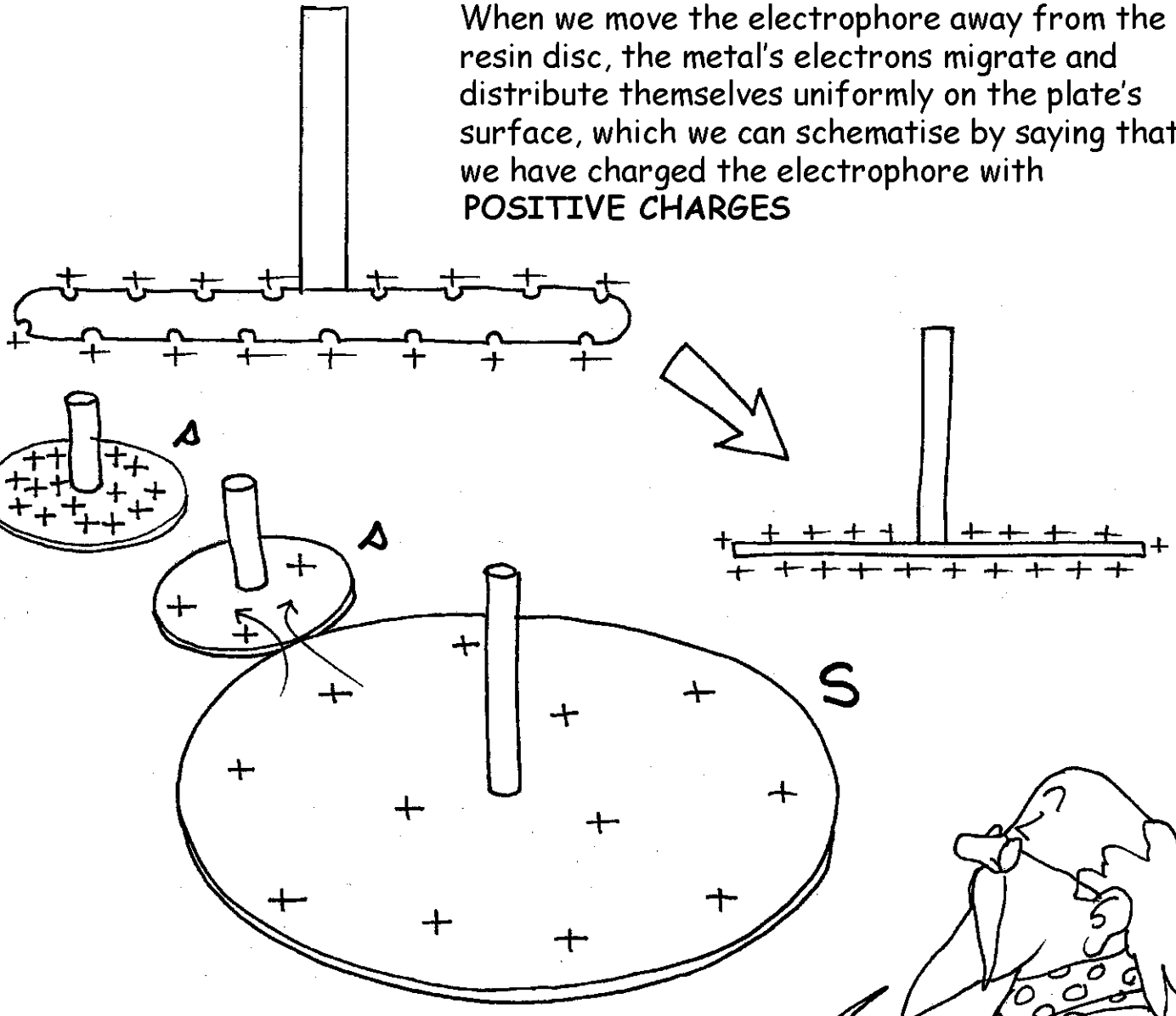
By opening tap R_1, we allow the overpressure reigning in B to evacuate into the immense capacitor T, which has a volume considered as infinite



In the same way, by putting the electrophore's tray in contact with the immense electric capacitor that is the **EARTH**, we allow the electrons to diffuse within this space.



When we move the electrophore away from the resin disc, the metal's electrons migrate and distribute themselves uniformly on the plate's surface, which we can schematise by saying that we have charged the electrophore with **POSITIVE CHARGES**

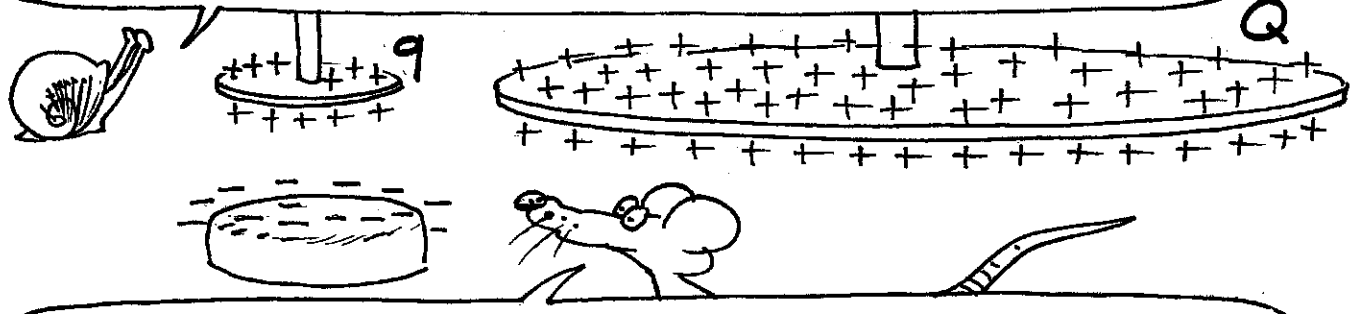


If we put our electrophore with a surface **s** having a surface capacitor **S**, the two devices share the "positive charges" in such a way that the densities of the charges by surface unit become equal. In fact it's the electrons of the large disc that migrate towards the smaller one. By repeating the operation we can thus bring additional charges, which will cease when the charges at the surface of the electrophore become equal to those of the **CAPACITOR** that it has charged.

This thing is great fun

I'm starting to understand the analogy with the barophore. With this, providing we operate a sufficient number of gas transfers, we can bring an enclosure with any volume to the same pressure as that existing in an enclosure **B**, when we extract it from its basin lodging

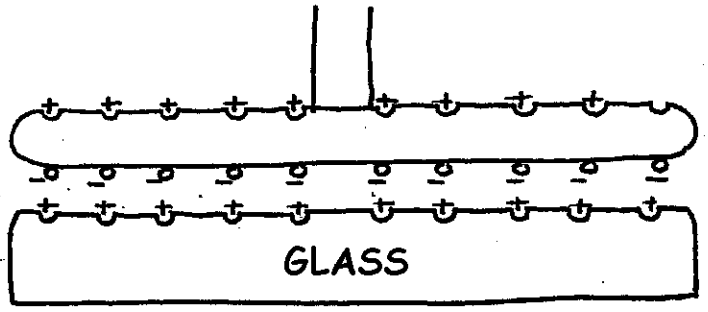
But what is the equivalent of **STATIC ELECTRICITY** ?



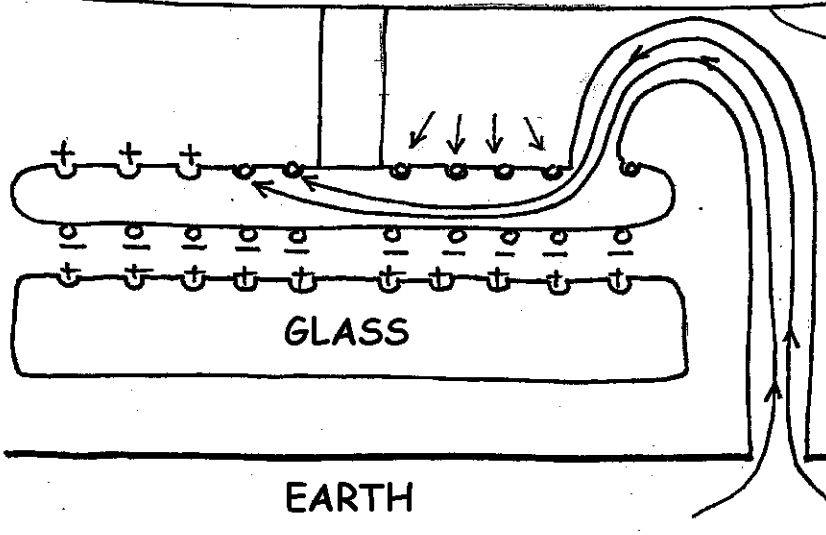
We could create on surface **S** of a capacitor the same density of electric charges as that existing on the surface of my electrophore, which is dependent on the electrification of the resin block.

But these electric charges, where do they come from ? It seems like a real magic trick

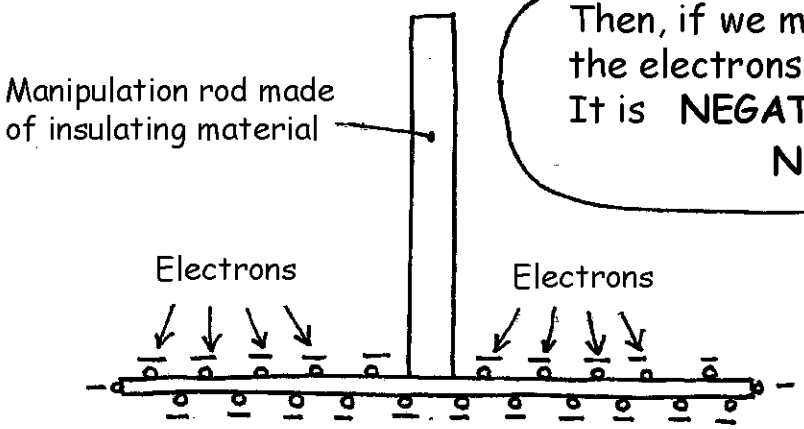
This trick, as you call it, allowed humans to go from small experiments that amused children, to far more serious things



And what happens when the electrophore functions with a disc of **GLASS** whose surface contains **VACANCIES** and which is therefore **POSITIVELY CHARGED** ?



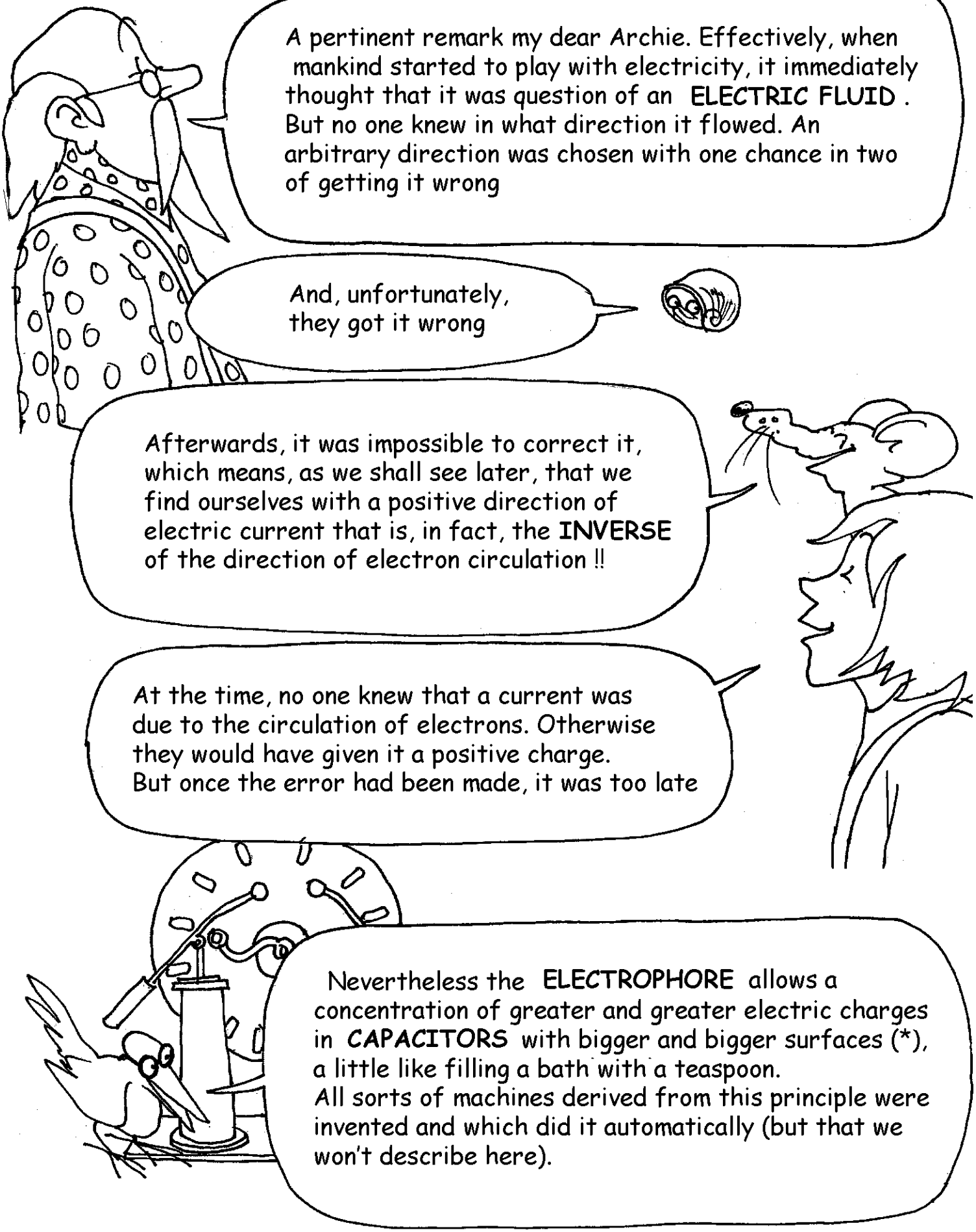
This time, when we connect the disc to **EARTH** , the electrons, attracted by positive vacancies, move upwards to fill and neutralise them



Then, if we move the electrophore away, the electrons migrate over the entire surface. It is **NEGATIVELY CHARGED** , it carries a **NEGATIVE VOLTAGE**

Wait, I'm lost ! The analogy with the **BAROPHORE** no longer works. The ELECTRIC FLUID is this sort of **ELECTRON GAS** (*). Here there is more, the plate, in overpressure, should be brought to a positive voltage shouldn't it?

(*) L'expression convient parfaitement



(*) The electric charge of a capacitor, for a given voltage, is proportional to its surface

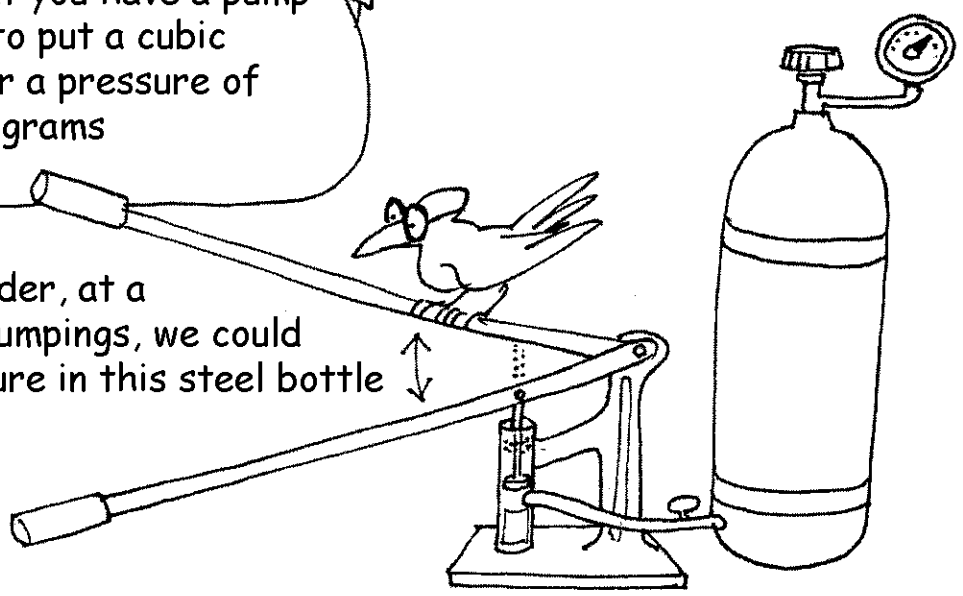
(*) **ATTENTION !** If you find plans on the **INTERNET** for an **ELECTROSTATIC MACHINE** that you can use to charge big capacitors, you might send yourself to the undertakers

Why is it that with a resin block, or rubbed glass, we can go from a simple toy to a system capable of killing a horse ? I admit I don't quite understand

Let us return to our BAROPHORE. With this you could carry a small volume B, with a pressure P. Then, progressively, carry a volume C, much greater, to the same pressure

Now imagine that you have a pump that allows you to put a cubic centimetre under a pressure of one hundred kilograms

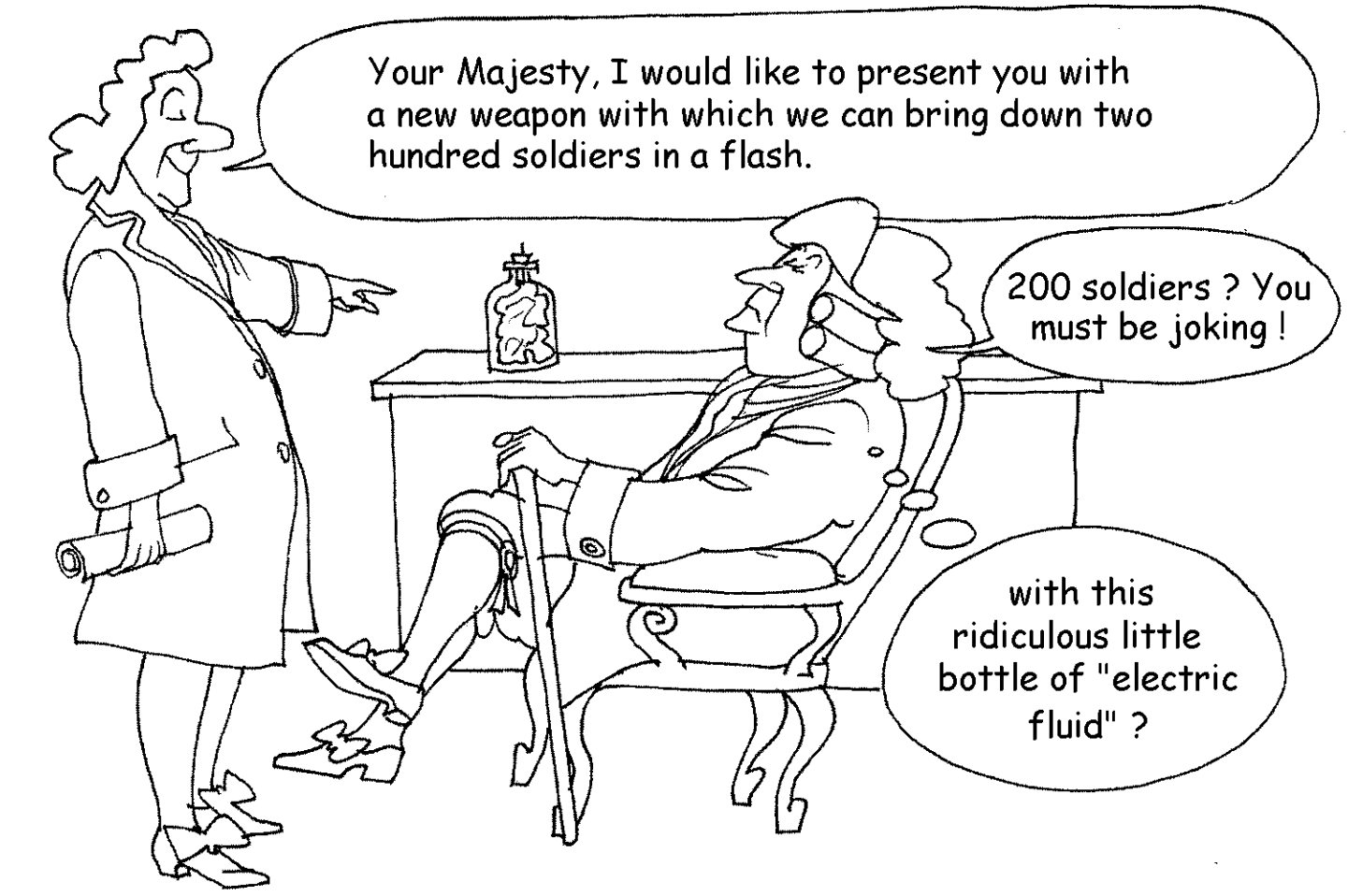
With this plunger cylinder, at a cost of thousands of pumpings, we could create the same pressure in this steel bottle

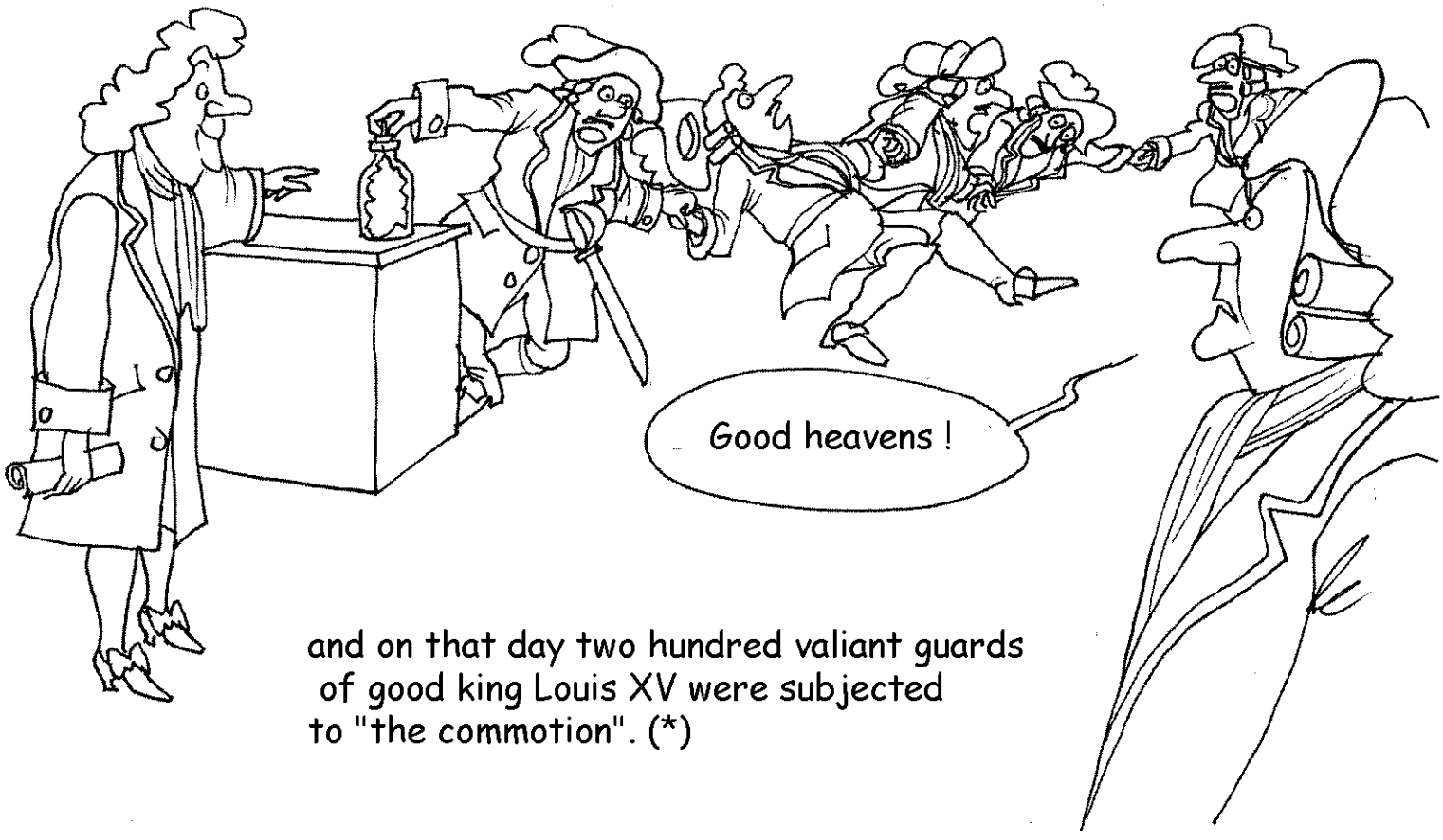


So, with enough time, I could therefore create the equivalent of a bomb (which it would become if the steel bottle broke).

In electricity, the equivalent of pressure is VOLTAGE, measured in volts.

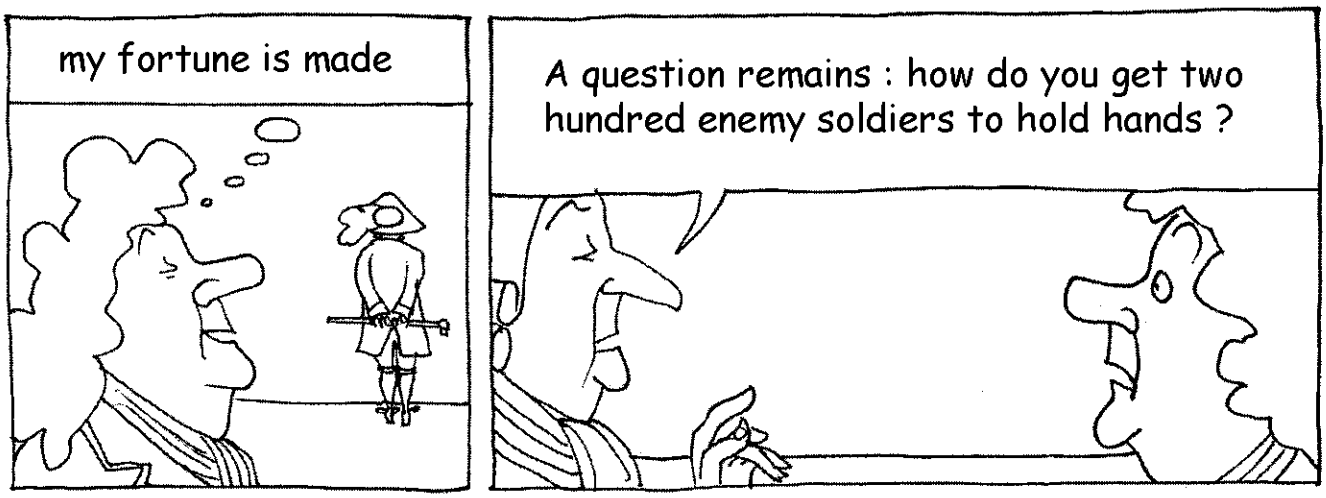
(*) **PRESSURE** is also an **ENERGY DENSITY BY VOLUME UNIT**



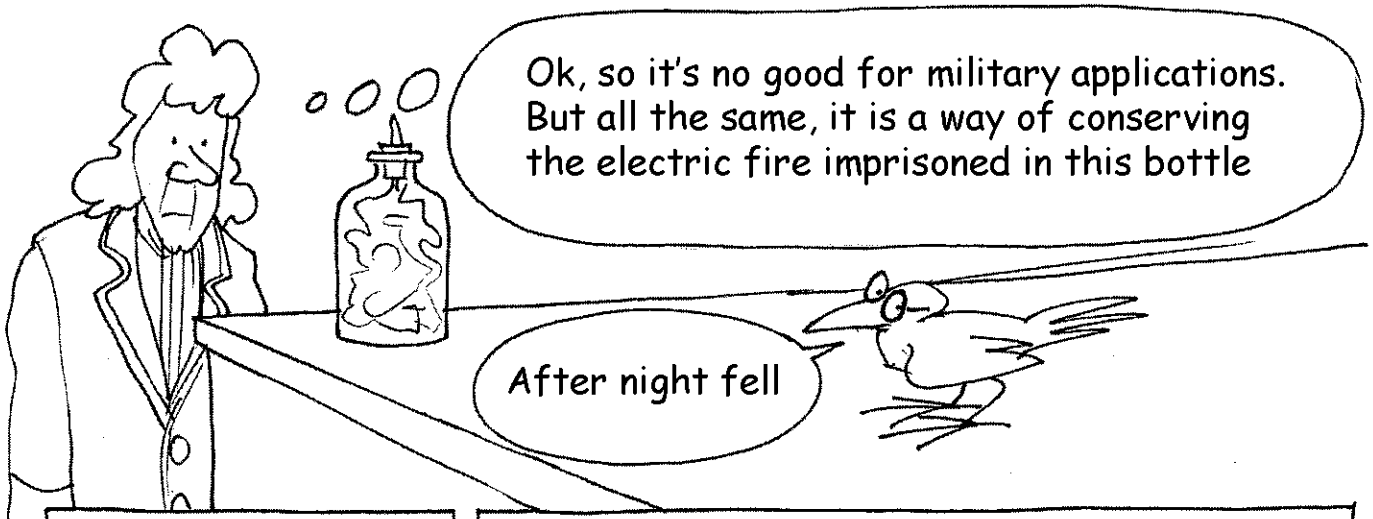


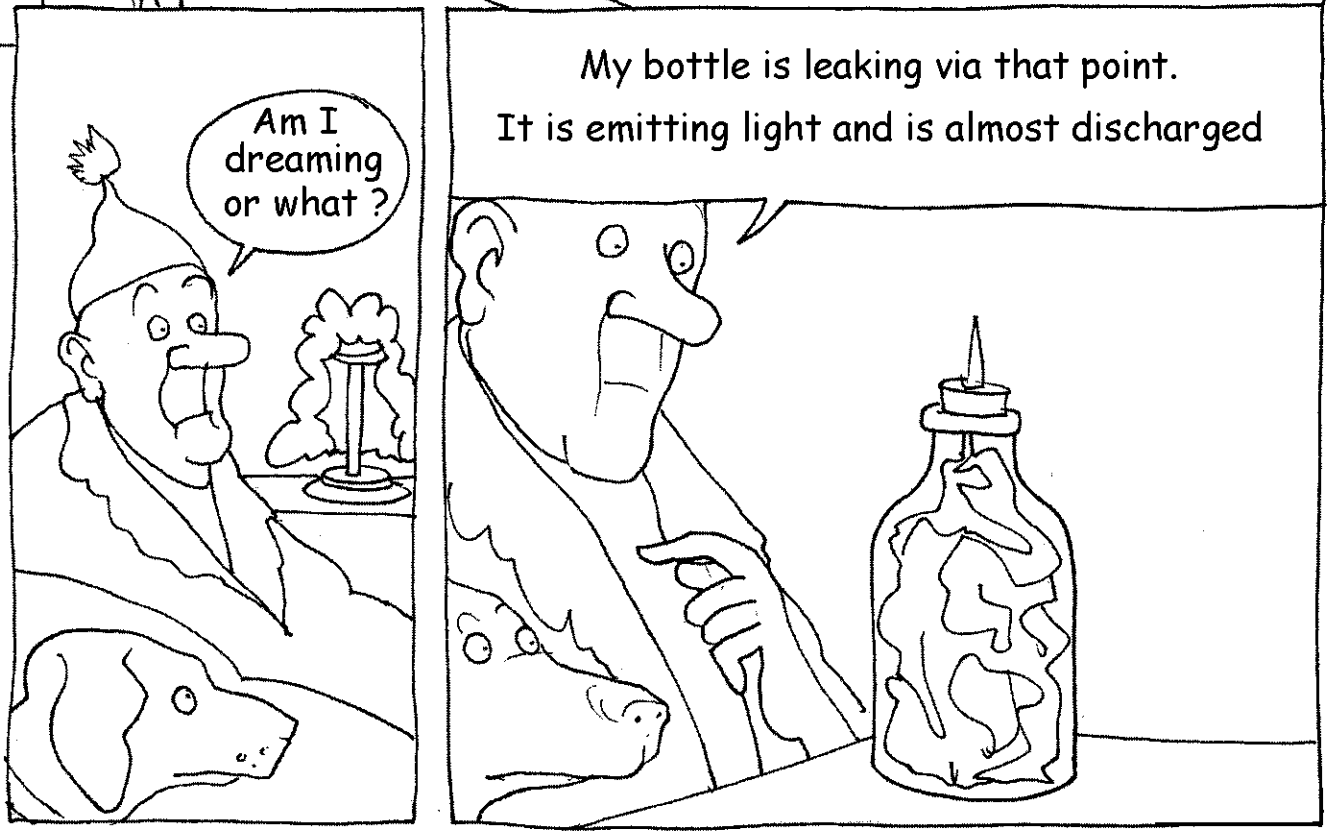
and on that day two hundred valiant guards of good king Louis XV were subjected to "the commotion". (*)

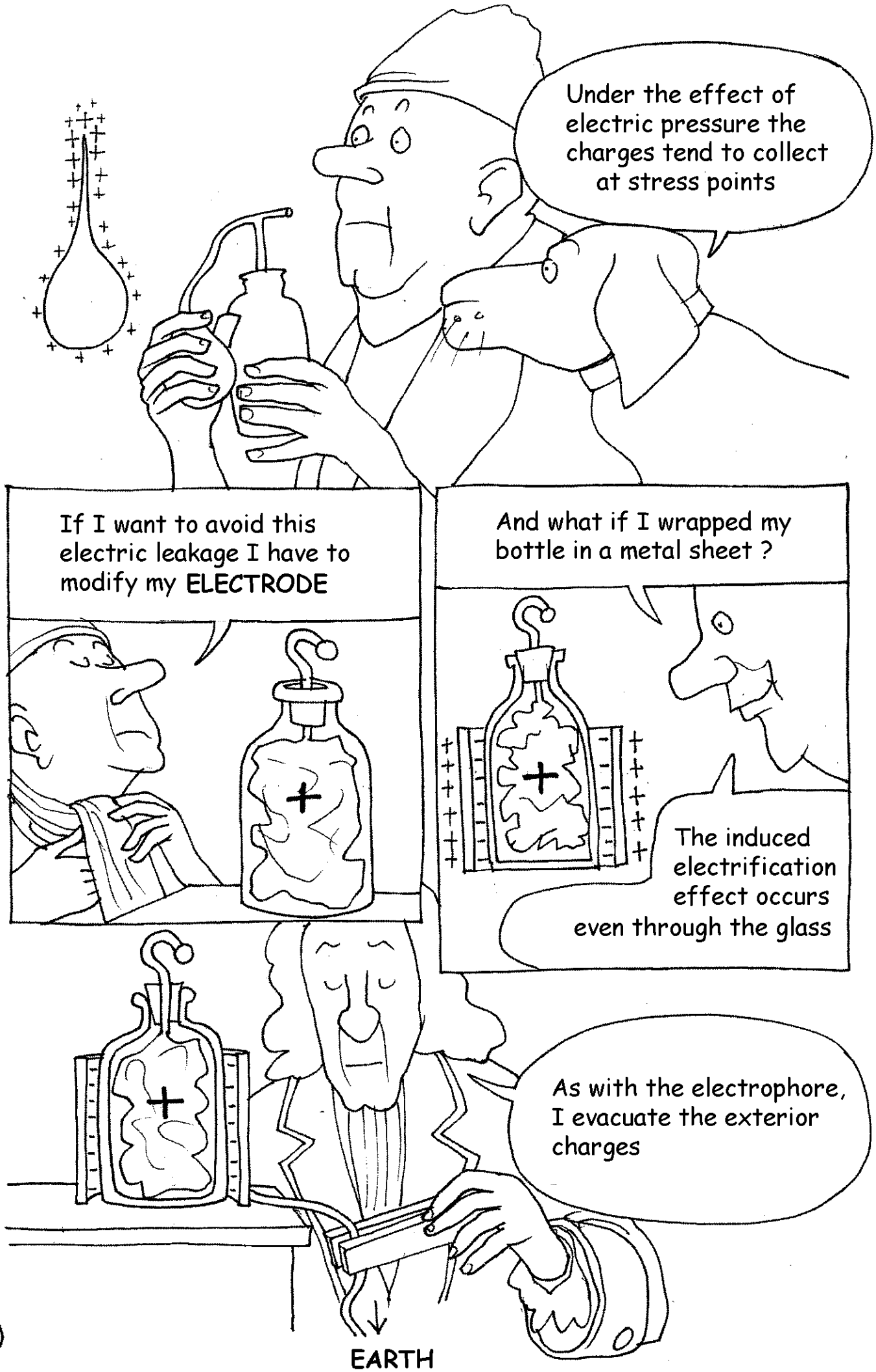
(*) In fact this experiment was conducted by Abbot Nollet in 1760



STRESS CONCENTRATiON EFFECT



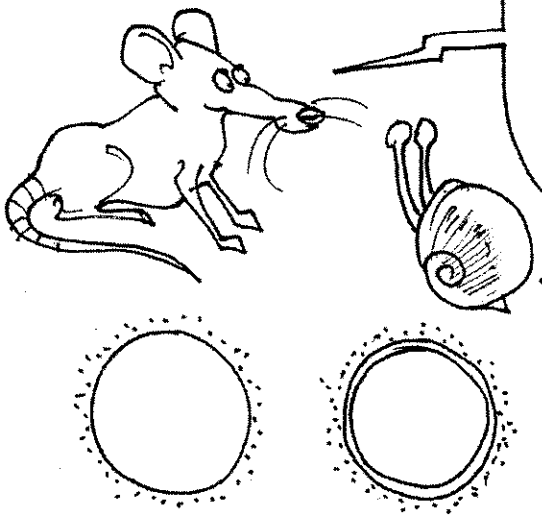



Under the effect of electric pressure the charges tend to collect at stress points
If I want to avoid this electric leakage I have to modify my ELECTRODE
And what if I wrapped my bottle in a metal sheet ?
The induced electrification effect occurs even through the glass
As with the electrophore, I evacuate the exterior charges
EARTH

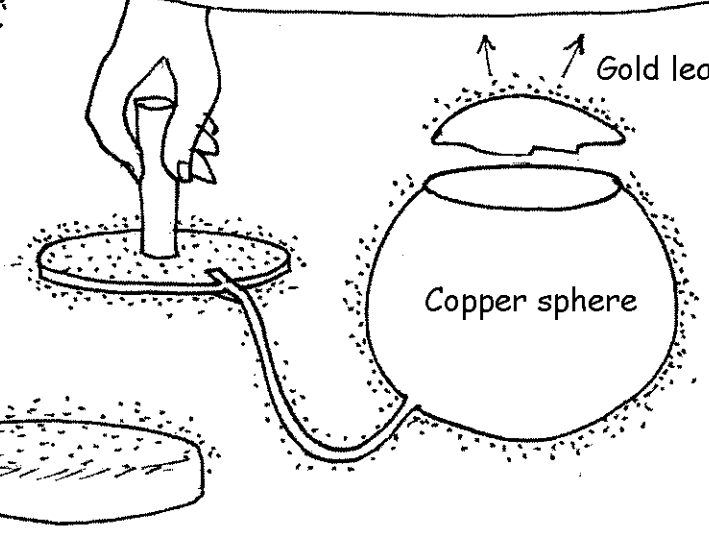
THE CAPACITOR

With this exterior plate, we double the electric charge. Thus, in 1746, in the fine Dutch town of Leyden, the **CAPACITOR** was born

Experiments continued, each more fascinating than the other. It was quickly noticed that when charged in the same way ("with the same voltage"), an empty sphere and a solid sphere received the same quantity of electric charge.

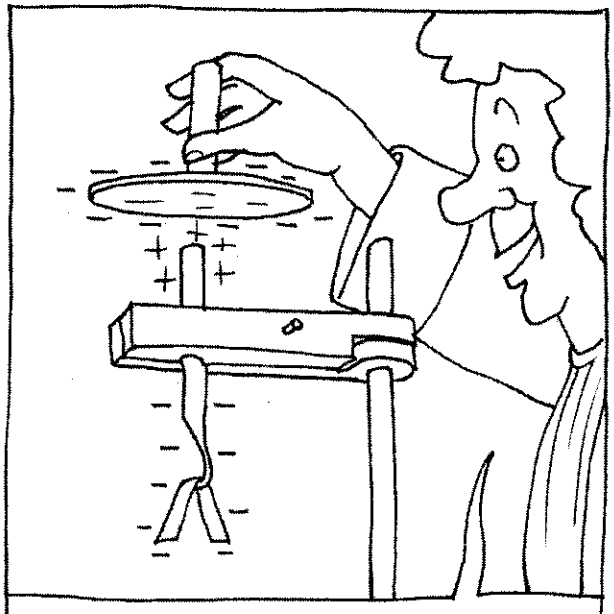


That's normal, because the electric charges are on the surface, because they repulse each other

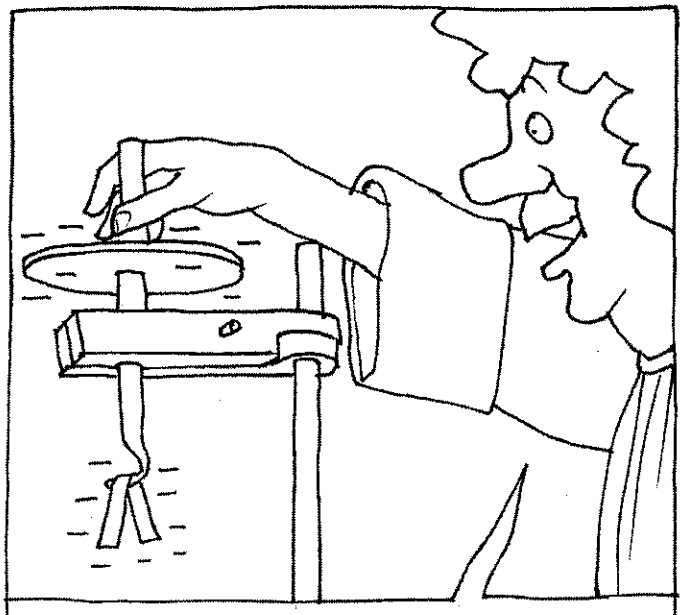


From this came an amusing experiment : when a hollow metal sphere was charged, closed by a small cap of gold leaf, this lifted itself up under the effect of **ELECTRIC PRESSURE**

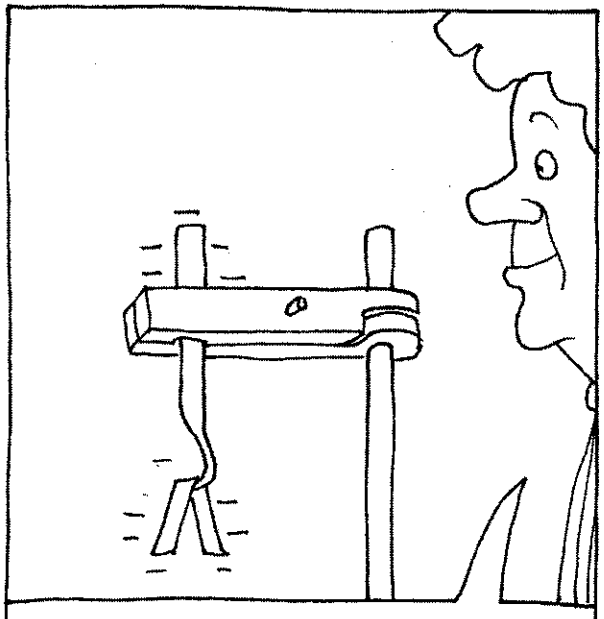
ELECTROMETER



Let us return to our earlier experiment. First : induced electrification

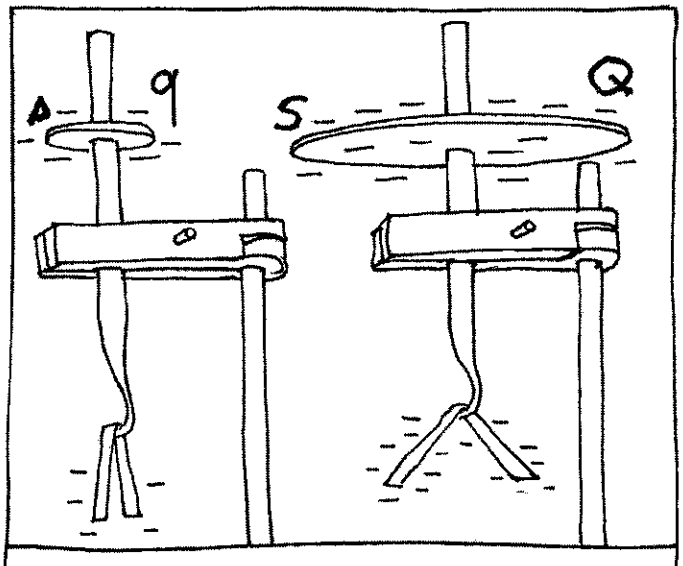


Secondly : neutralisation of positive charges or ... sharing negative charges



Thirdly :

I remove the charged object. A negative charge subsists, which keeps the leaves separated.



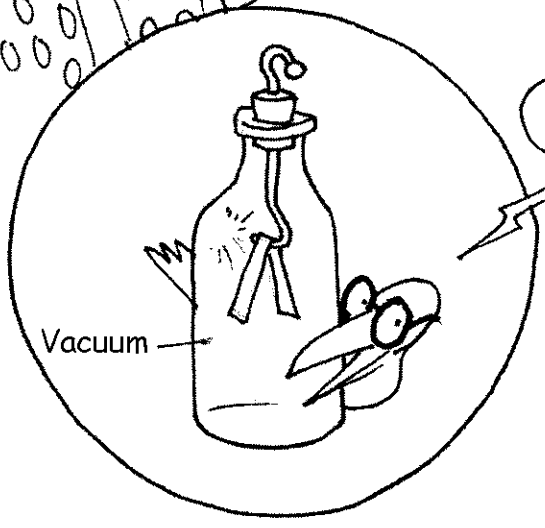
By using the same charged resin disc, these two electrophores, their surfaces **s** and **S**, carry charges **q** and **Q**, proportional to them. The distance of separation of the gold leaves is related to this.

This device is called a gold leaf electrometer. The gap between the leaves gives us an idea of the electric charge contained in any metallic object, but does not allow us to know the sign of the charge.

Will it keep the charge indefinitely ?

Air isn't a perfect insulator, especially if it is damp. With timethe charges will be lost into the atmosphere.

In laboratories, the gold leaves are kept in a vacuum.

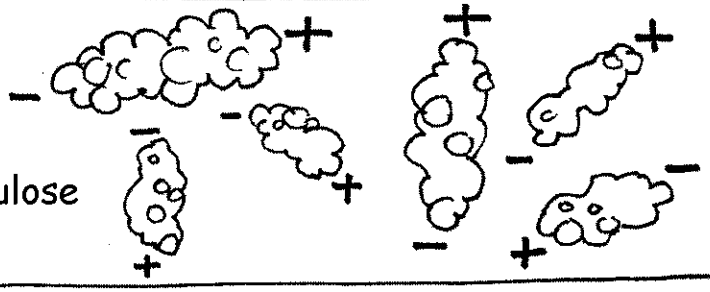


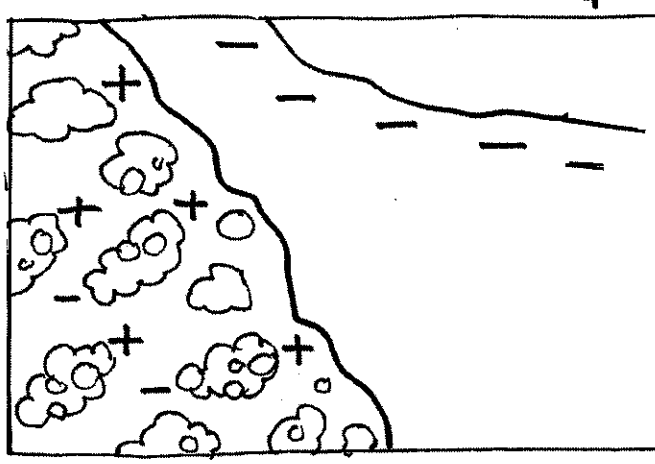
Grandad, I understand that we can electrify my perspex ruler by rubbing it, but I don't understand why it attracts paper

A good question

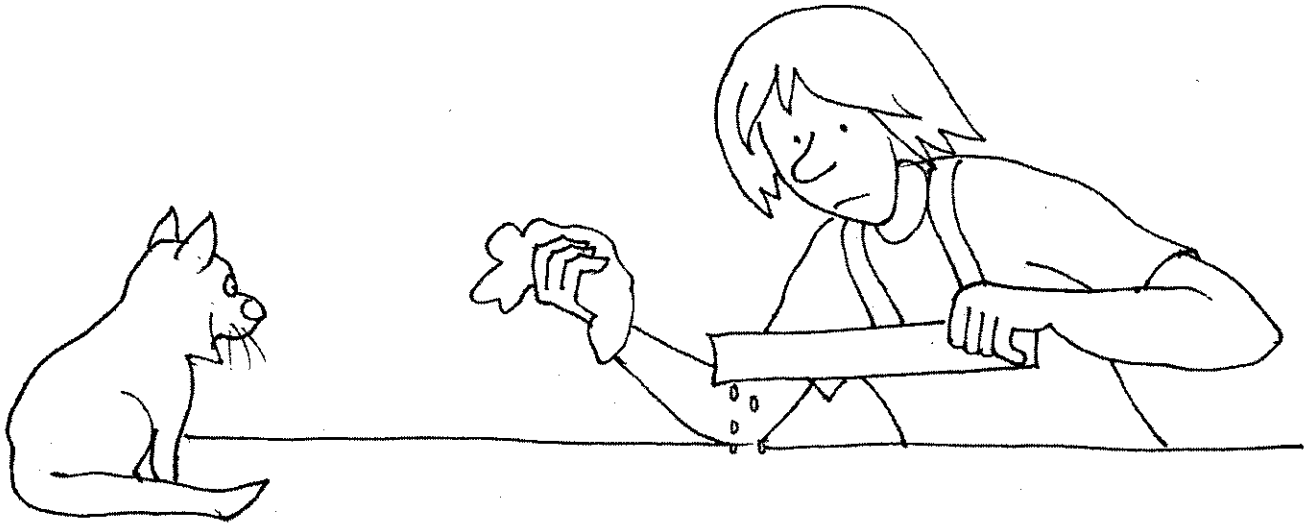
POLARiSATiON

As you saw, in olden times people attracted balls of the light wood, we call Elder. Like paper, this contains molecules of cellulose (*) which present themselves in the form of **ELECTRIC DIPOLES** with a + charge at one end and a - charge at the other



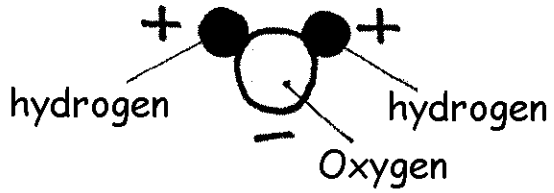


Confronted with an object having electric charges, these molecules turn, directing themselves towards the opposite charges of those carried by the object. An **ATTRACTION** results

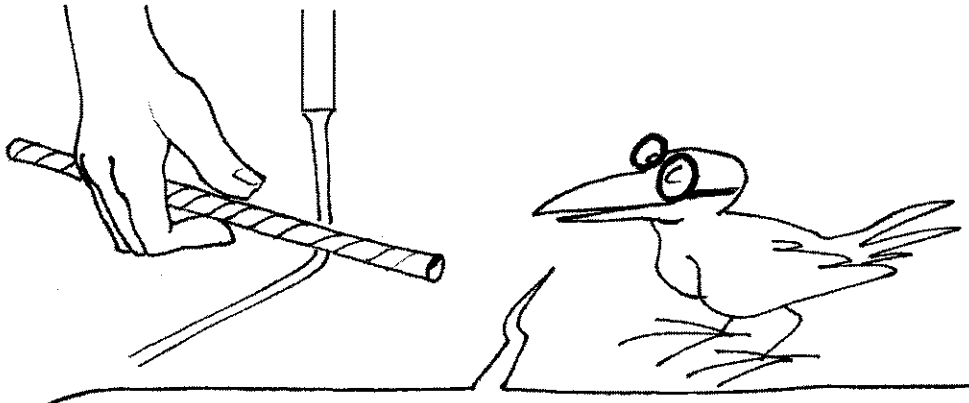


(*) Paper is made from wood fibre

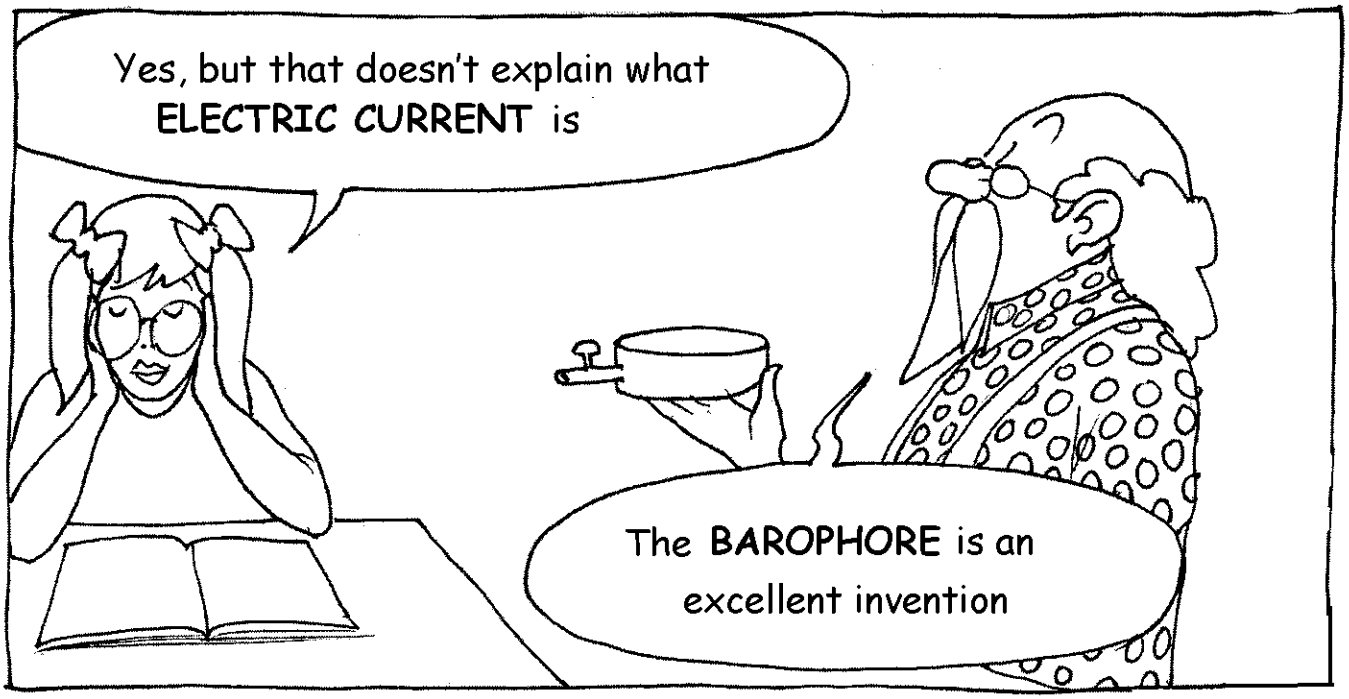
The water molecule is the "Mickey Mouse molecule"

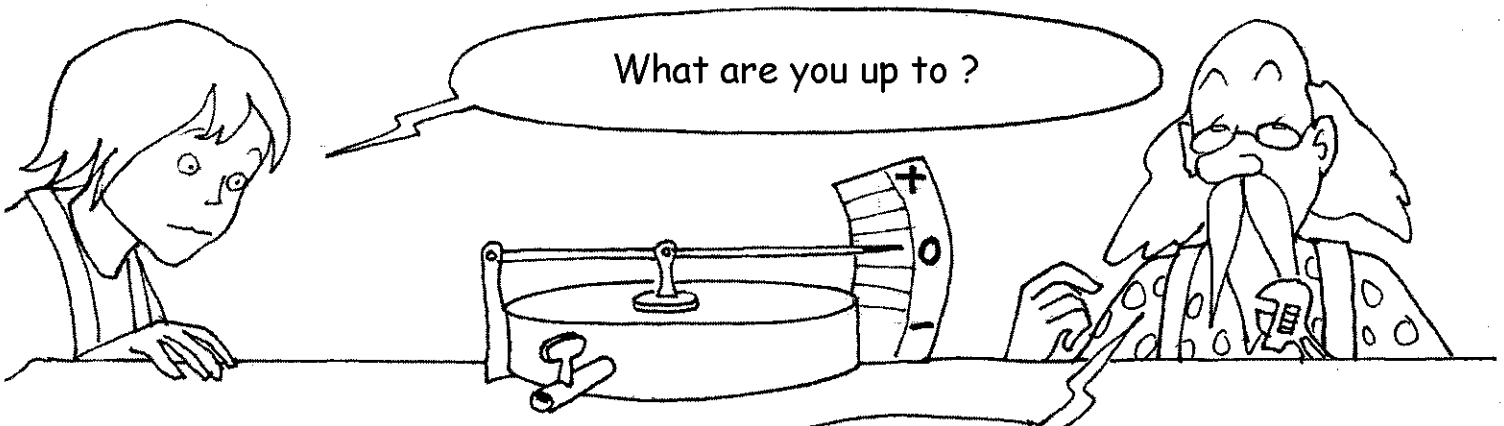


Subject to the action of an electrically charged object,
a water molecule orients itself and a force of attraction results.

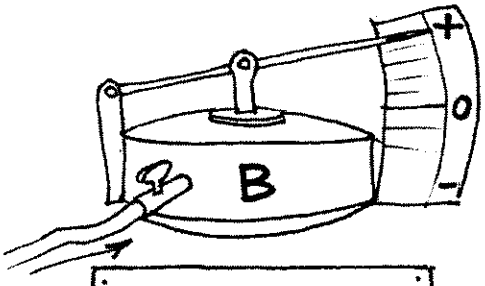


By rubbing one taken from a fast-food outlet, the sort that sell rubbish hamburgers, and by bringing it near a tiny trickle of water, we can make it bend at a ninety degree angle

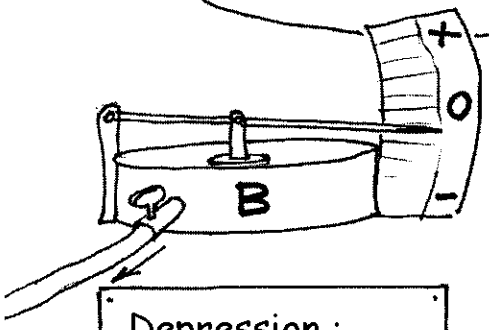




a **barometer**



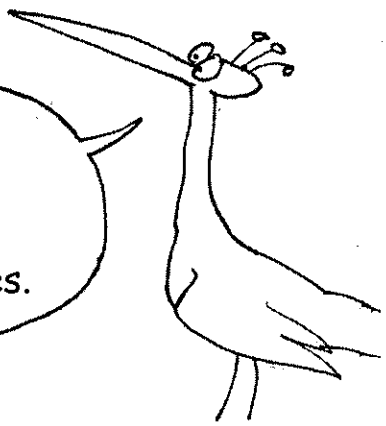
Overpressure : positive tension in the membrane



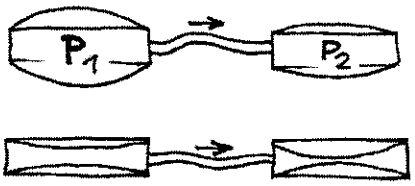
Depression : negative tension in the membrane

Pfff ... it's well-known, it's a membrane manometer

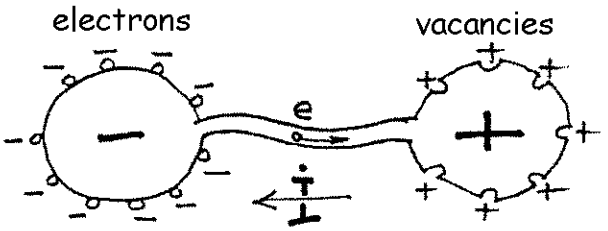
We obtain a gaseous current if we connect the two enclosures B_1 and B_2 , one having a positive tension and the other, a negative tension.

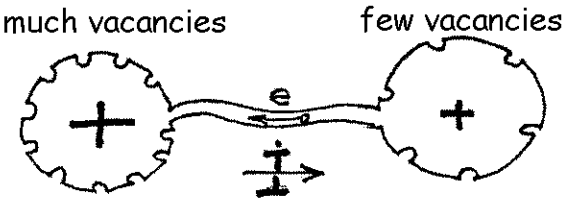


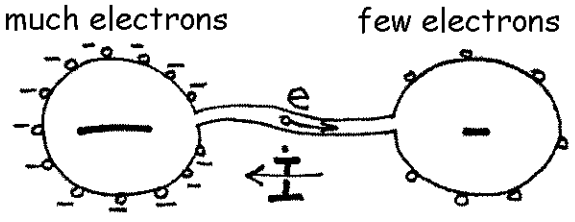
But in fact, what provokes the establishing of a gaseous current is the **DIFFERENCE BETWEEN THE PRESSURES** P_1 and P_2 or the **DIFFERENCE IN THE TENSIONS** V_1 and V_2 of the two enclosures.



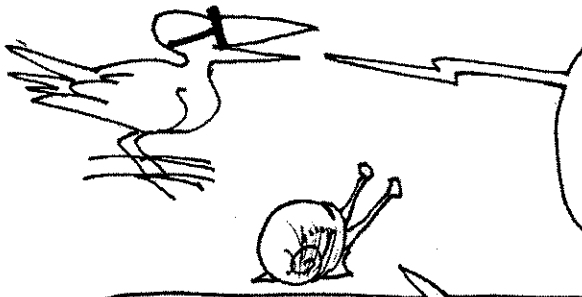
Between the two enclosures, the gaseous current will be established from the high pressure to the low pressure even if the two pressures are lower than ambient pressure.







As well as all intermediary situations

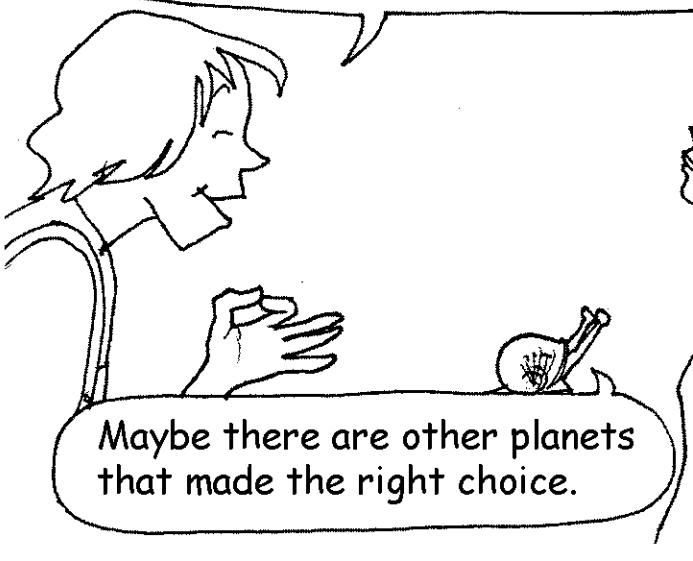


We find all these configurations among positively charged capacitors (absence of electrons) or negatively charged ones (excess electrons)

To sum up, the charged particle flow is always established from the medium richest in electrons towards the poorest medium. And as people got it completely wrong two centuries ago, it just remains to **INVERT THE DIRECTION** of this **GAS OF FREE ELECTRONS**

It was a very stupid error. There was one chance in two...

Now, if we wanted to play around and change the direction of the **ELECTRIC CURRENT** we would have real trouble. We've decided not to bother



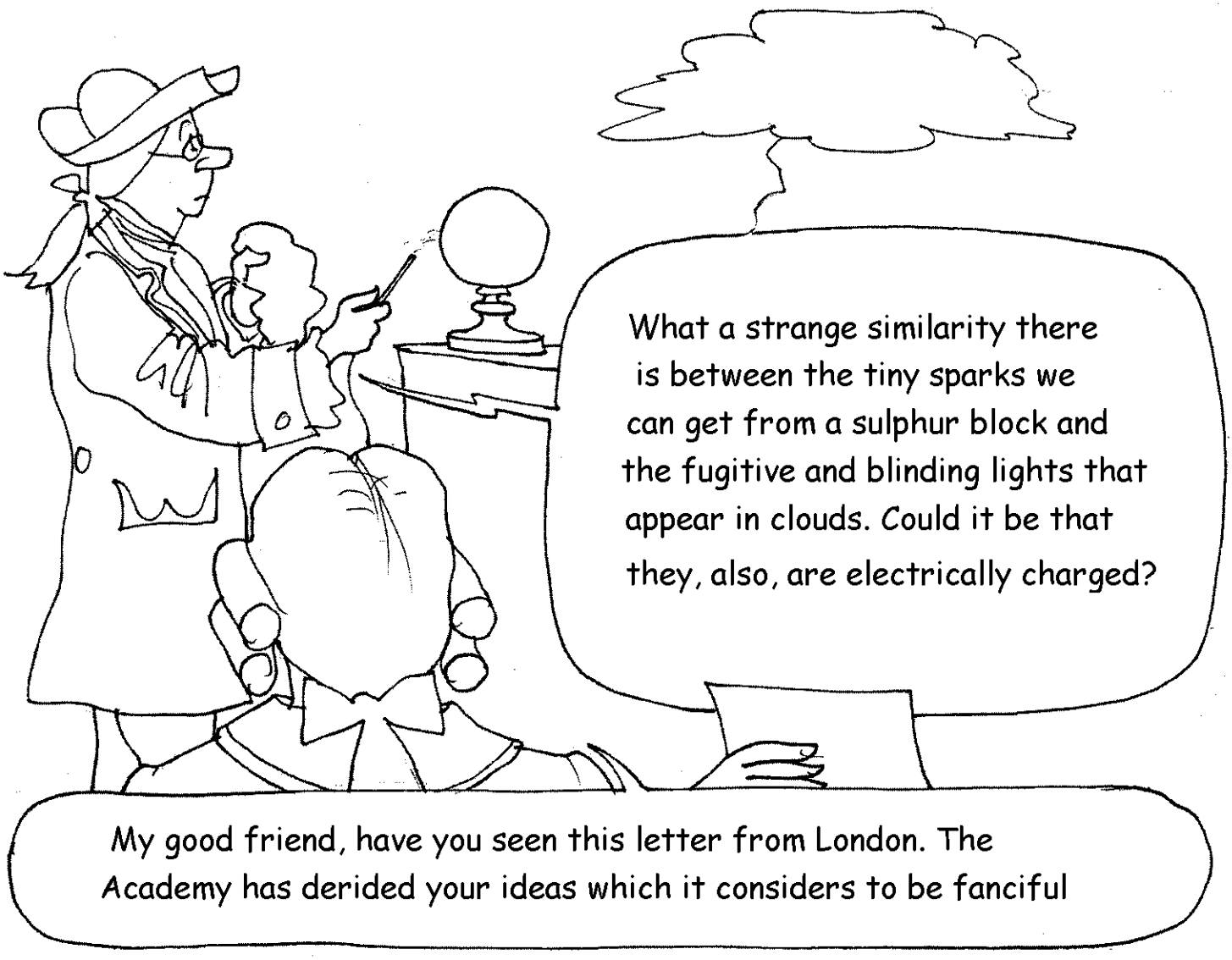
Maybe there are other planets that made the right choice.

It's probable

(*) Capacitors are the worst energy storing systems imaginable, with the biggest sets we have today, we can barely make enough tea for four people.

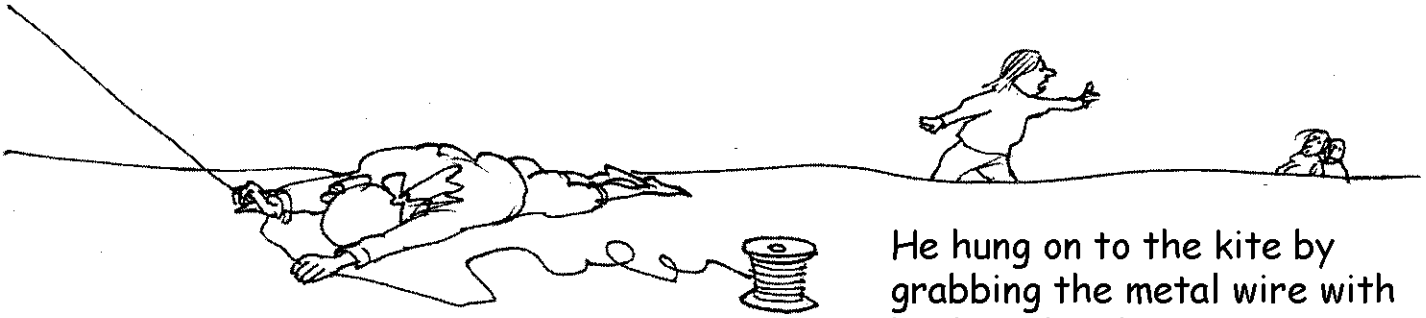
ELECTRICITY IN NATURE

Benjamin Franklin in Philadelphia in 1750

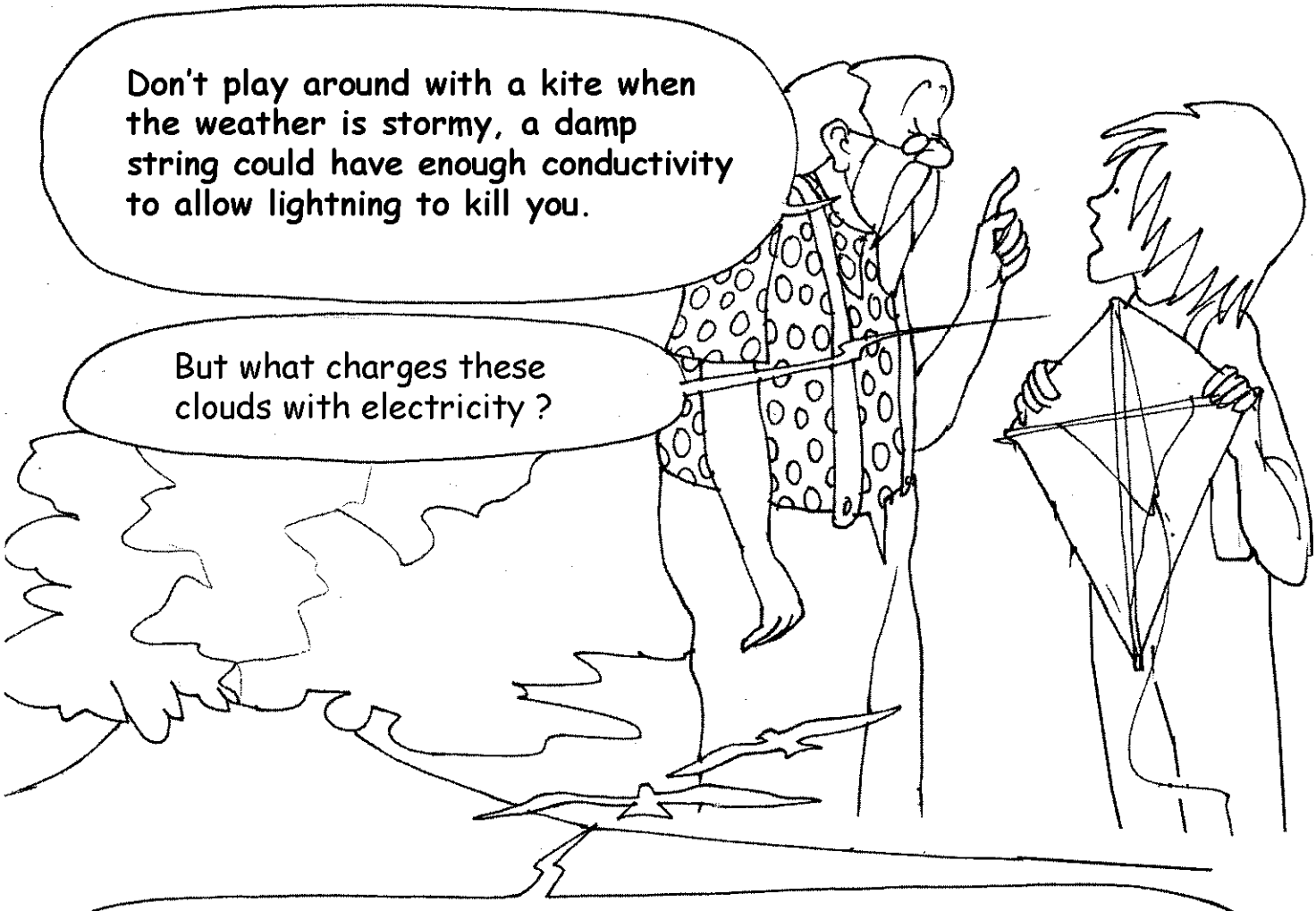


(*) which partly melted the key

Benjamin Franklin was right and those who mocked him were wrong, the news spread like wildfire. But many experimenters were not as prudent as he and so, a little later, Georg Willem Richman, in St Petersburg, was the first person ever to be … electrocuted

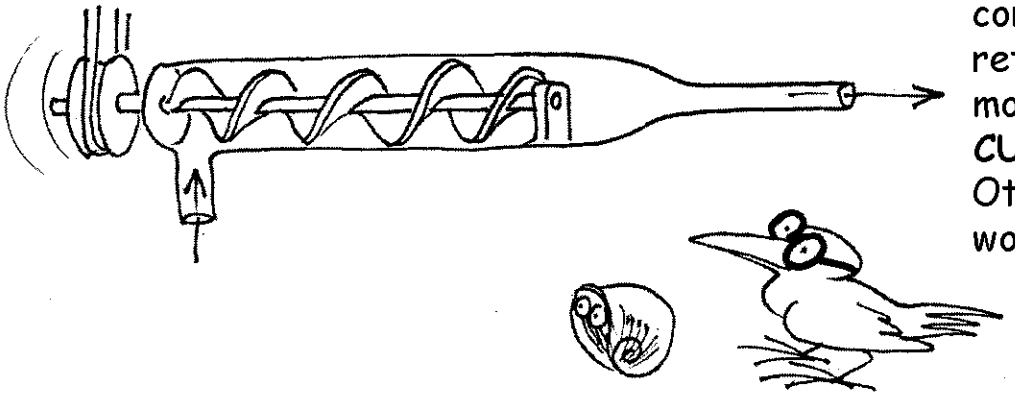


He hung on to the kite by grabbing the metal wire with his bare hand

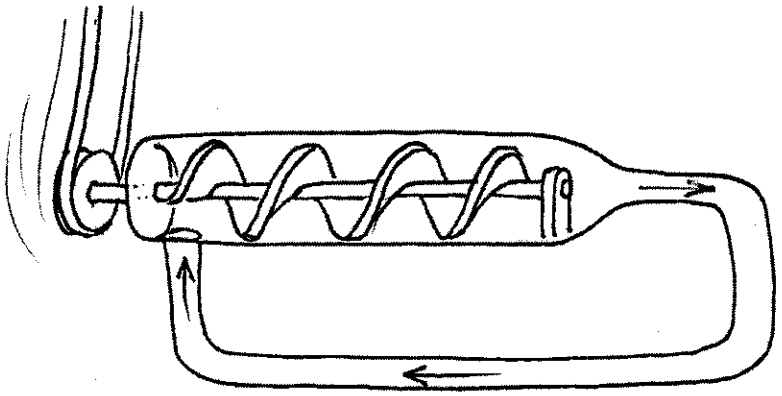


It's **TRIBOELECTRICITY** again, the rubbing together of two substances. In volcano clouds, fine dust swirls around in the gas. The dust becomes electrified and powerful flashes shoot through it. In clouds, tiny ice crystals, falling in a powerful ascending current, are electrified and so charge the cloud mass.

Let us summarize up to here. It all began in the 5th century BC when Thales, rubbing pieces of amber, attracted small objects. Thirteen centuries later, when interest in science was beginning in Europe, people began to rub anything they found : resin, glass ... They learnt to accumulate electric charges in capacitors, first by hand, then using machines capable of delivering dangerous commotions. But it wasn't until the creation of **ELECTRIC CURRENT** sources that the "electric magician" found a place in human activity, other than as a simple "curiosity". The first source derived its energy from chemical means. It was the **BATTERY**, invented in 1800 by the Italian Alessandro Volta. Then Gramme, Tesla and many others invented machines that converted mechanical energy into electric current. The description of their principles is outside the scope of this book. So for us, an **ELECTRIC GENERATOR** can be considered as "an electron pump". (*)



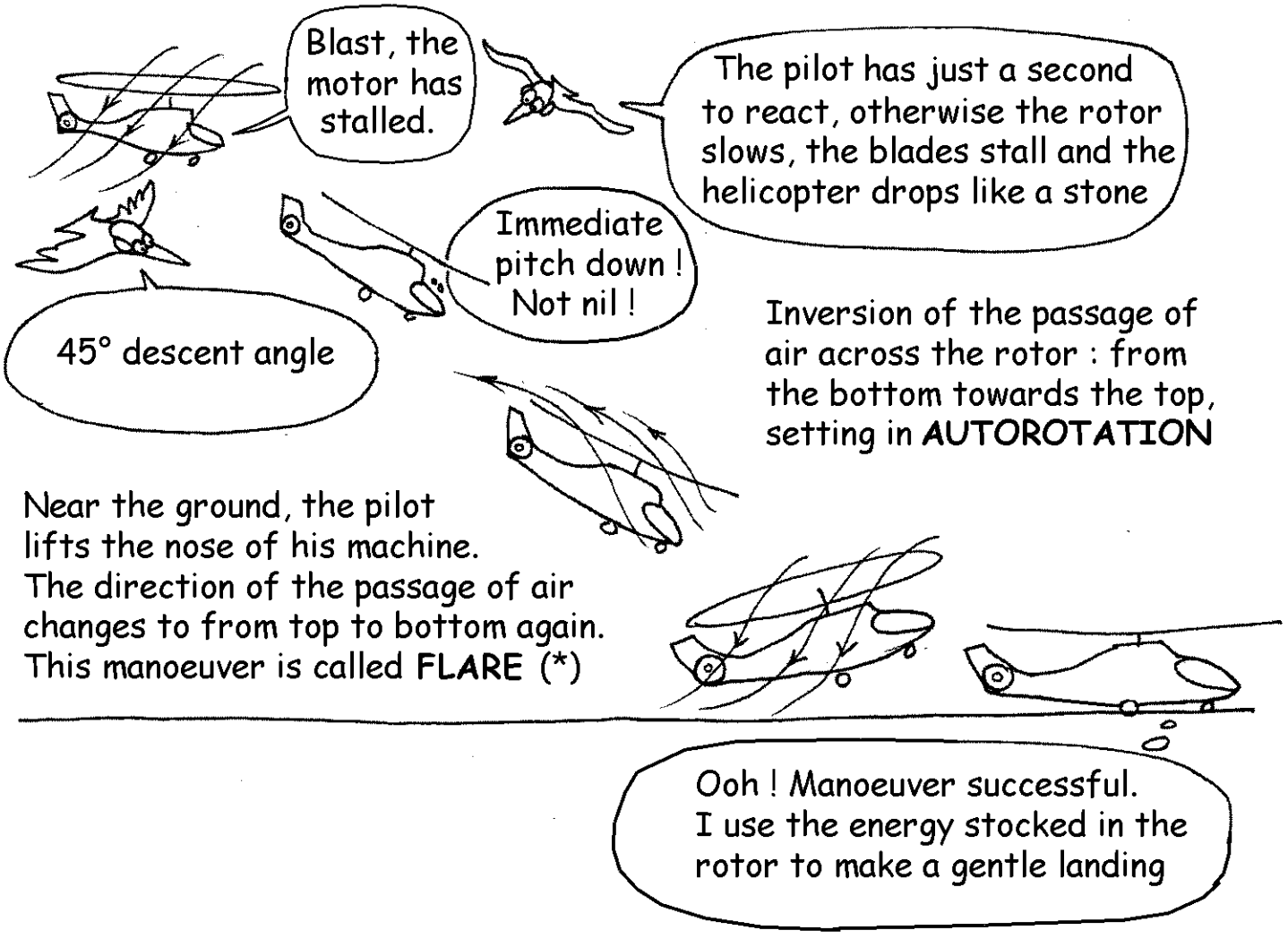
A pump can only function continuously if there is a return of the fluid it moves, that is to say a **CURRENT LOOP** Otherwise it will be working on nothing



(*) An "electron pump", remembering the error made during the 18th century, gave rise to "electric current" the opposite direction of electron circulation.

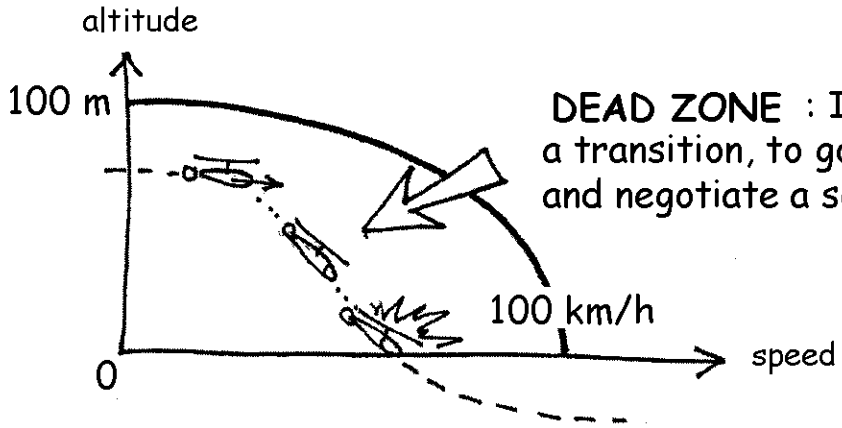
DiRECT CURRENT

The sources of domestic **DIRECT CURRENT** are (non-rechargable) batteries and **ACCUMULATORS** (rechargable) such as are found in cars and which take care of all its equipment and **WIRELESS** systems. The automobile industry is developing **HYBRID** systems or accumulators, continuously recharged by conventional motors, which can thus work at maximum efficiency and give reduced consumption. The Franco-Australian, Pascal Chrétien (*), is the pioneer of the hybrid helicopter, using a system which reduces a major fault with such flying machines : they are incapable of landing in autorotation. A helicopter can **GLIDE** in its way, but at the cost of a delicate **TRANSITION**



(*) Pascal Chrétien : pascal.chretien@swissmail.org
(*) Vertical Passion : Free download at :
http://www.savoir-sans-frontieres.com

But this manoeuver can only be effected if, at ground level, we have a speed of 100 km/h, or if speed is zero at 100 metres altitude, or, if in an intermediary situation, the machine is in the

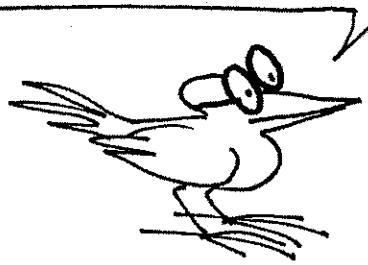


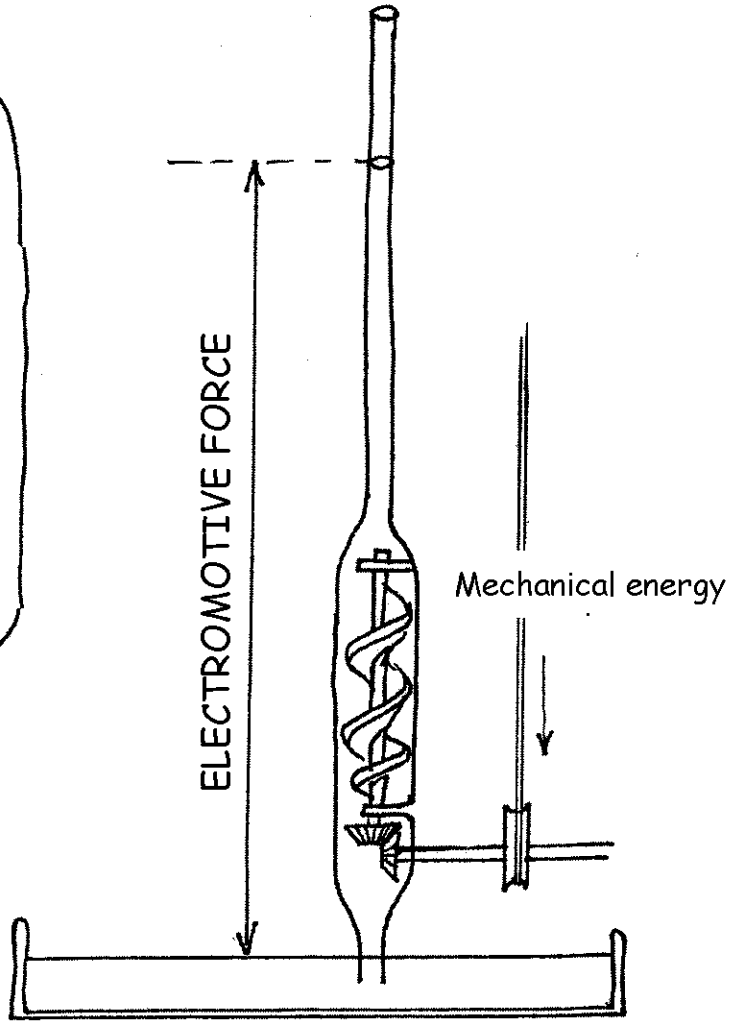
DEAD ZONE : Impossible to effect a transition, to go into autorotation and negotiate a soft landing

However, most of the time, helicopter pilots operate "in the dead zone". The fact of permanently conserving a reserve of energy in a battery allows them to overcome a deficiency of their conventional motor, an electric motor takes over, so removing this inherent risk to helicopters (*)

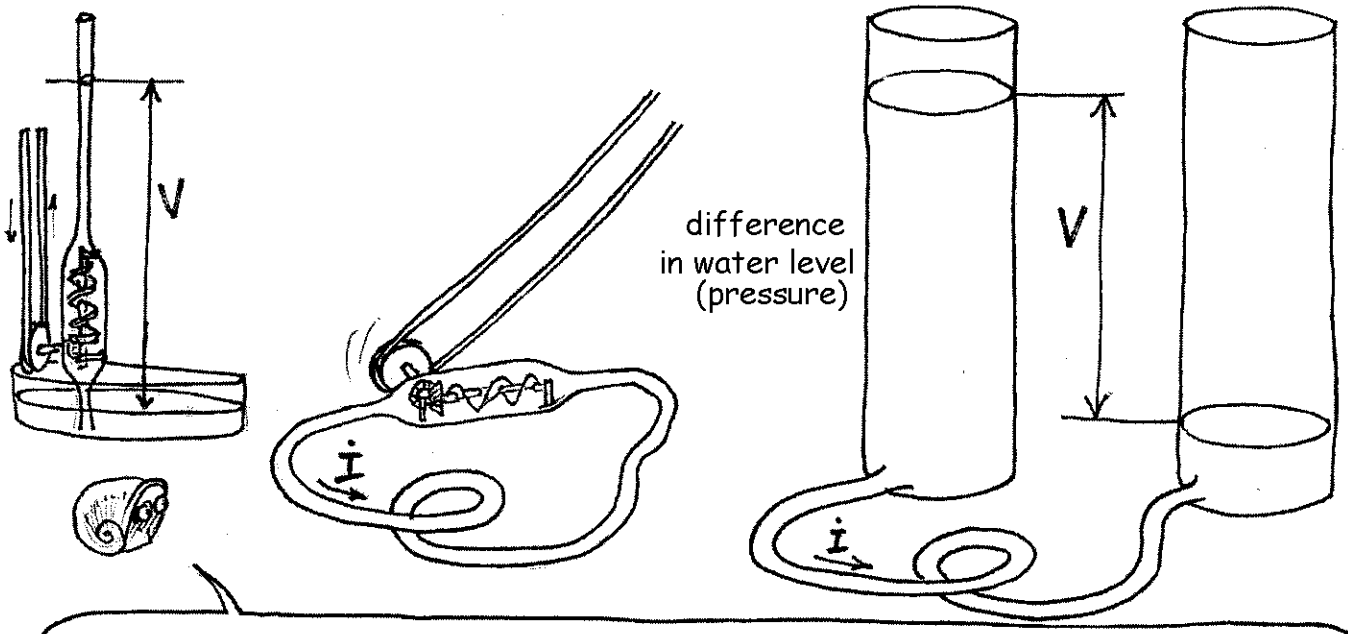
Let us return to direct current. An electric generator is an electron pump, capable of supplying an "electronic pressure", called **ELECTROMOTIVE FORCE** . If we compare this generator to a water pump, the image will be the height (equals : pressure) to which the pump can raise the fluid, in

" **OPEN CIRCUIT** ".





(*) An idea of Pascal Chrétien (2002)

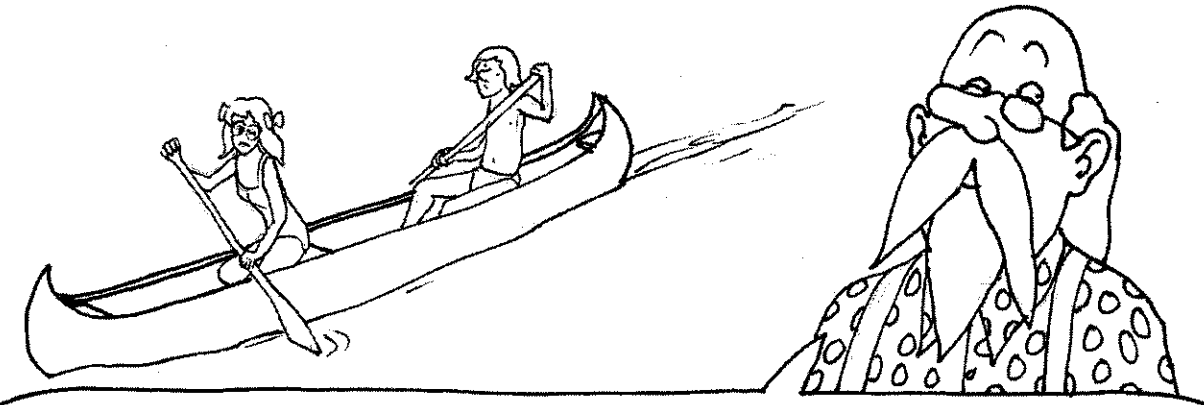


By attaching a hose with a cross section s and length L, we obtain the same flow I (analogous to electric voltage) by connecting it to a pump (analogous to an electric generator) or to two reservoirs presenting a difference in water levels, identical to the lifting power of the pump (analogous to **ELECTROMOTIVE FORCE**)

Remaining with the hydraulic analogy, what limits the water flow I in a given tube, for a difference of water level V, also fixed (or an admission pressure delivered by the pump) ?

It's the **FRICTION** of the water on the wall of the tube

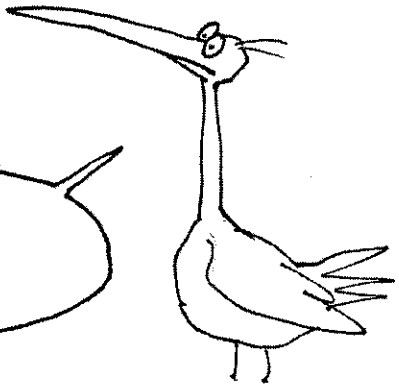
You mean that the water rubs against ... the inside of the tube ?



When you paddle a canoe on a lake, you and Sophie, you have to push hard on the oars to overcome the friction of the water on the hull. And when you stop paddling, your canoe quickly stops moving doesn't it?

In doing so, **ENERGY** is being used, it's **TRANSMITTED** to the fluid.
After that, where does it go? What does it become ?

Well, it makes eddies.
Let us call it turbulent energy



Yes, but these eddies end up by disappearing.
So in the end, **WHAT** does this energy become?

It is changed into **HEAT**. When paddling, in effect, you are heating the water in the lake. Not much, because water has a great **CALORIFIC CAPACITY**

Friction is the phenomenon by which nature transforms mechanical energy into thermal energy, heat. That's what happens when we rub our hands together. We can even melt ice by rubbing it

Seriously ?

When you are on a gentle ski slope and you have to exercise a small pressure to begin sliding, it isn't to "unstick the skis" but to melt a thin layer of snow, which is in contact with the skis, by means of the heat emitted by friction. So we don't ski on snow but on a thin film of water, which then refreezes immediately

That's given me an idea

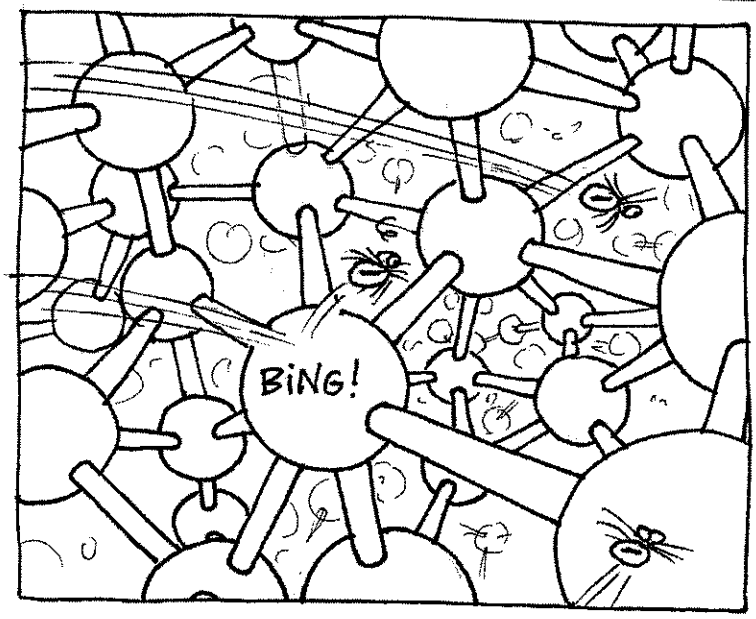
Marie, did you know that when you stir mayonnaise with a spoon, you are increasing its temperature?

Oh not much, because mayonnaise has a high calorific capacity

What has that got to do with electricity ?

RESiSTANCE

Surely you're not going to tell me that the electrons moving in an electric wire rub against the insulating wrapper around it



The network, fixed, of metal atoms forms obstacles which slow the progression of electrons. Because they're constantly colliding with these obstacles, they transmit energy to them

But how can metal atoms acquire energy when they can't move ?

It's the entire network that begins to vibrate

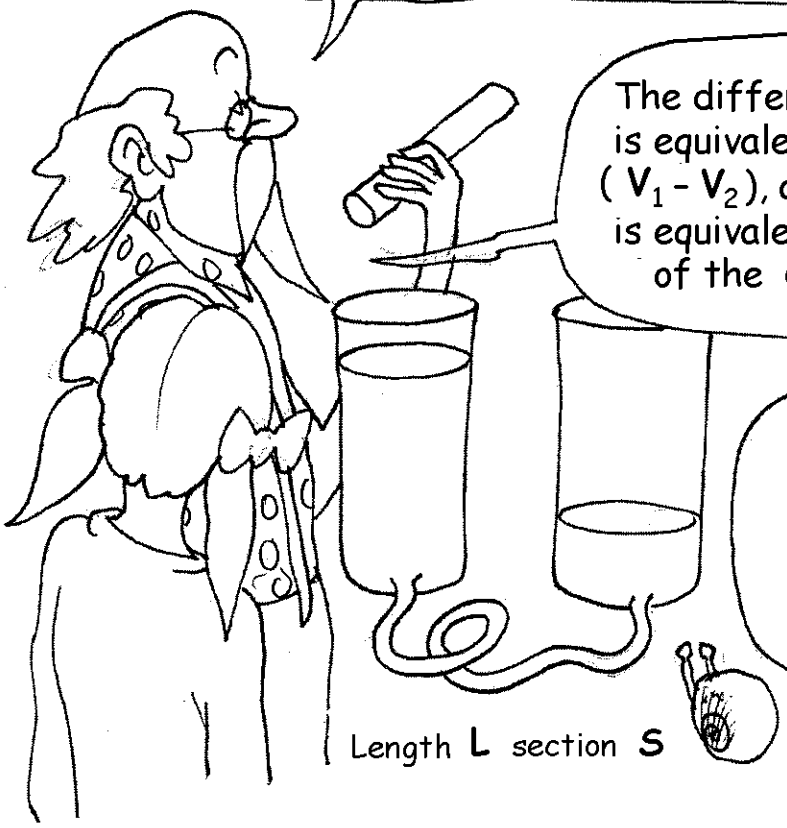
When I put an iron against my cheek, I don't feel any atoms vibrating

Yes but the atoms in your cheek feel them

If we wanted to make a complete analogy between electricity and hydraulics, we would have to make liquid circulate in a **POROUS MILIEU**, whose porosity was equivalent to the **CONDUCTIVITY** (*) of an electrically **CONDUCTIVE** material

The differences in pressure (P_1 - P_2) is equivalent to the difference of potential (V_1 - V_2), and the **FLUID CURRENT** flow is equivalent to the **INTENSITY I** of the electric current

So the question would become : for a pressure difference $V = P_1 - P_2$, with a conduit of porosity $\pi = 1 / \rho$, of a given length **L** and section **S**, what will the output I be ?



1) The greater the porosity π (or electrical conductivity σ), the higher the flow (electric current)
2) The longer the tube, the more liquid (or electricity) can pass
3) The smaller the section : the same thing

What would you say to a law such as :

$$\text{Flow } I = \frac{\text{difference in pressure } (P_1 - P_2)}{\text{resistivity } \rho \times \text{length } L \ / \text{ section } S}$$

It's a very nice law. And what do we get when we transpose it to electricity ?

(*) RESISTIVITY is the opposite of CONDUCTIVITY

In electricity, the formula is equivalent in every way : **I** (electric intensity) = (V_1 - V_2), difference of potential divided by **RESISTANCE** ($\rho L/s$)

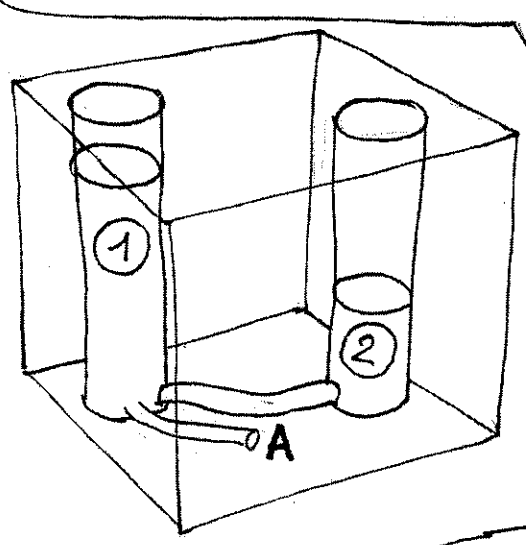
In other words, resistance to the progress of a fluid in a tube is calculated with a formula similar in every way to that which allows the calculation of electric resistance in a wire.

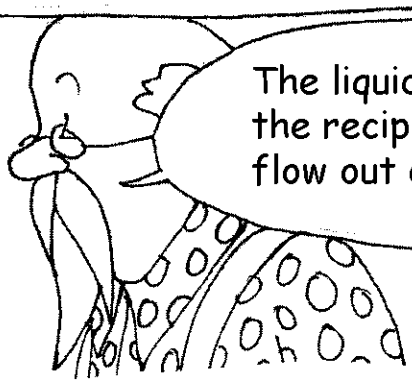
R

Hang on. There is something I don't understand in this hydraulic analogy. To make a liquid flow in a tube, or a porous conduit, I don't need to have two reservoirs with different levels.

But if we put one of the two wires "in the air", the current no longer flows.

You're forgetting something : air isn't a **CONDUCTOR** , but an **INSULATOR** . If you want to complete your analogy, you'd have to drown the assembly in a plastic material, perspex.





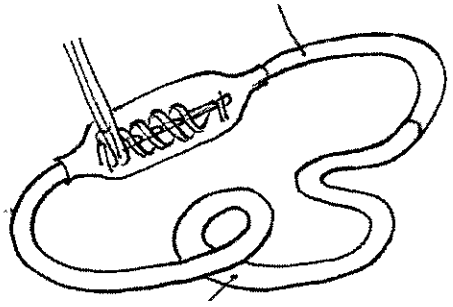
The liquid contained in the recipient 1 cannot flow out of the hole A.

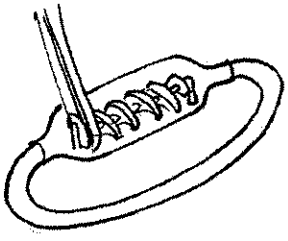
INTERNAL RESISTANCE

But if I **SHORT CIRCUIT** the metal blades of this battery, shouldn't there be an intense current and an instantaneous discharge ?

No, because every electric generator, whatever it be, possesses an internal resistance, non nil, that imposes a maximum limit on the current it can give out

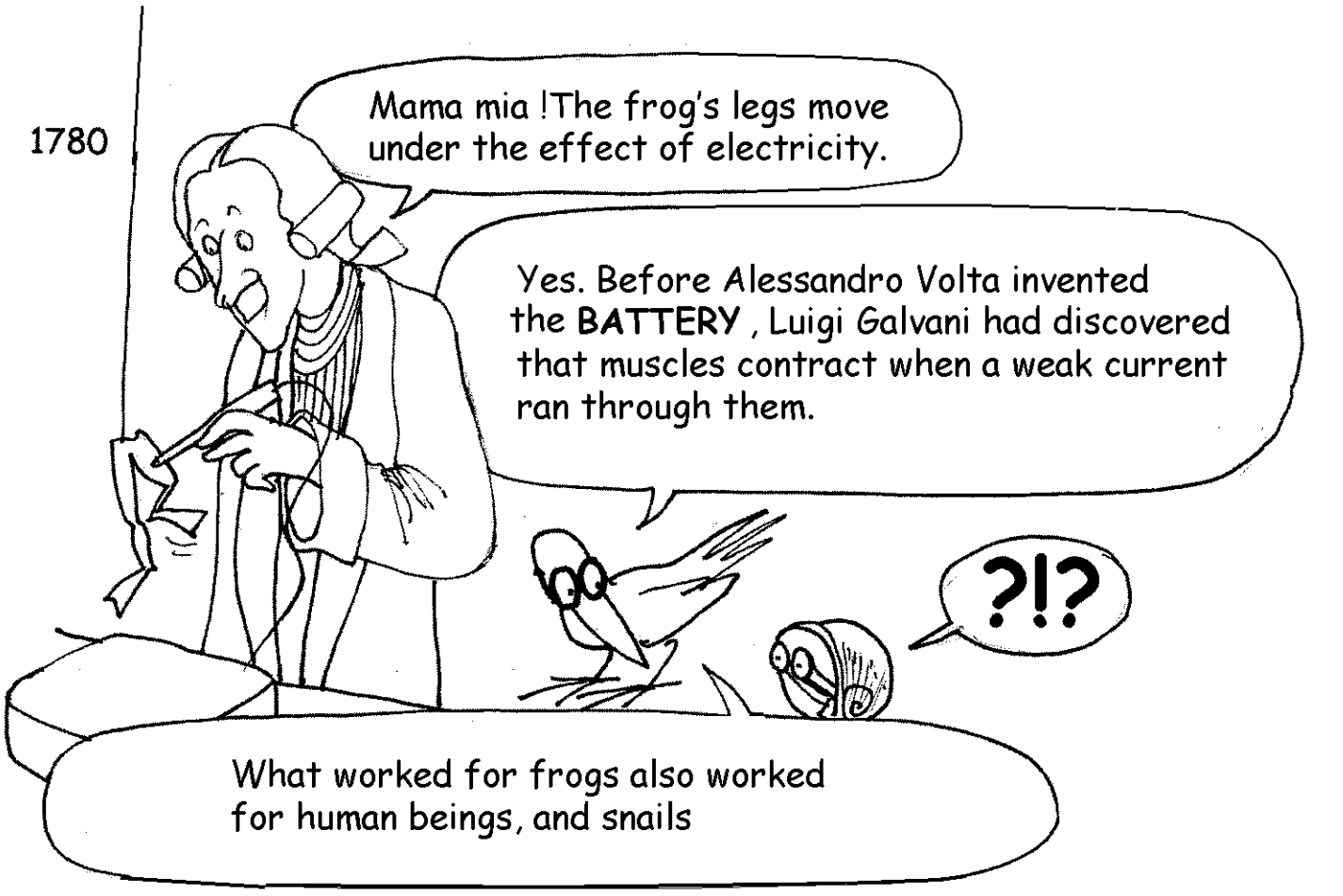
INTERNAL RESISTANCE

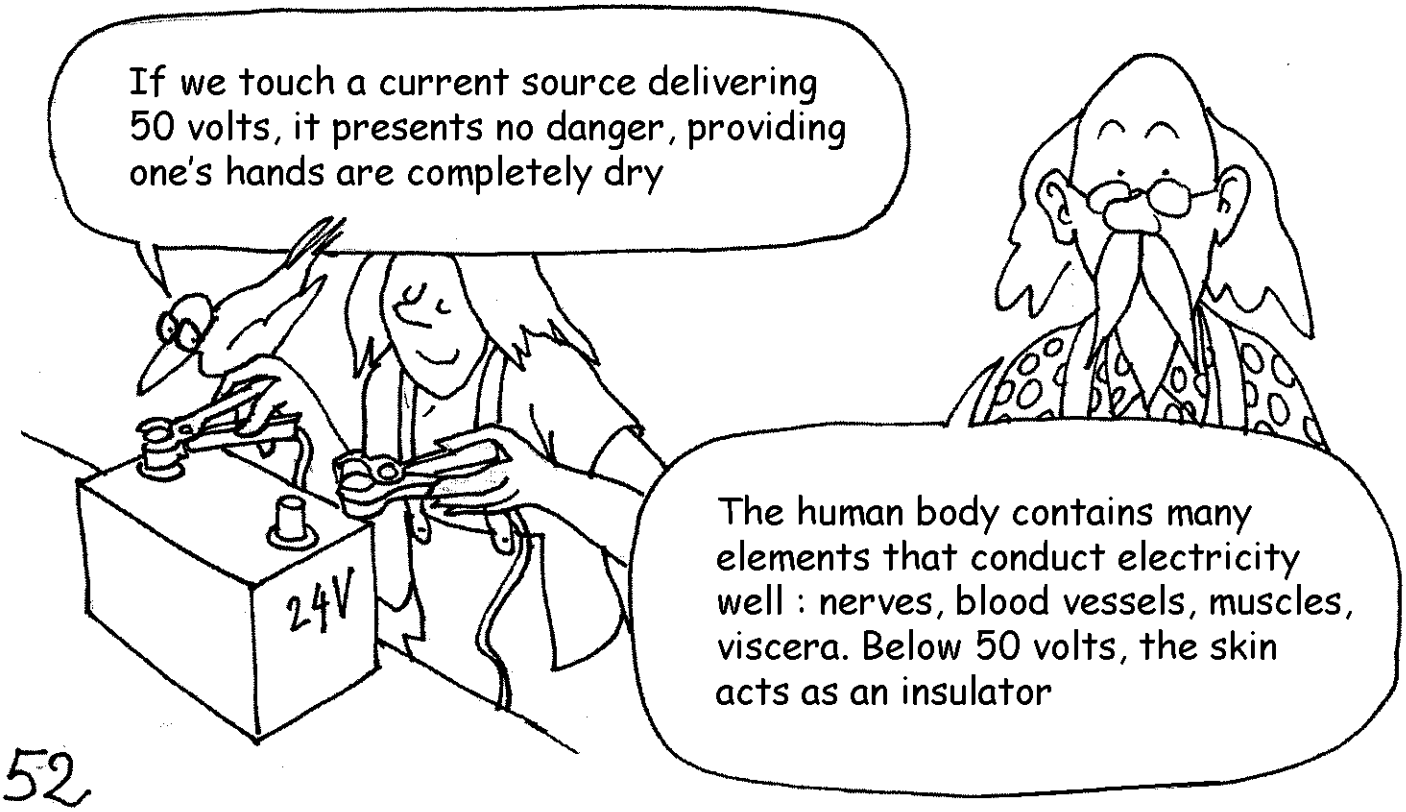


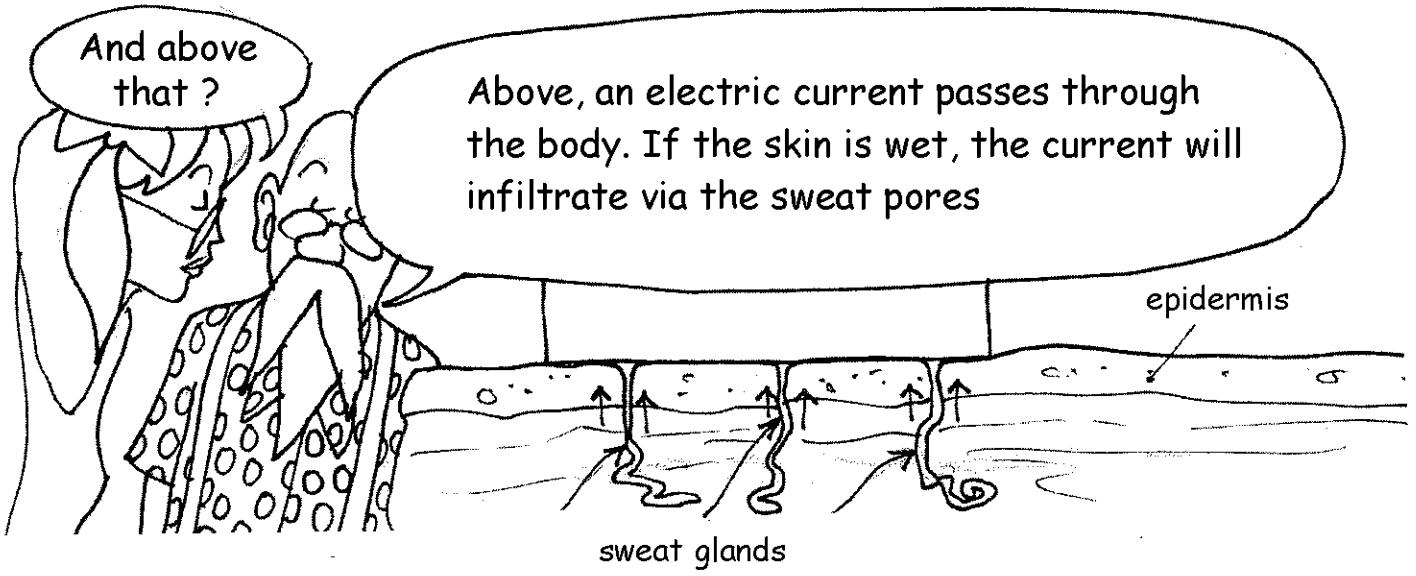


EXTERNAL RESISTANCE

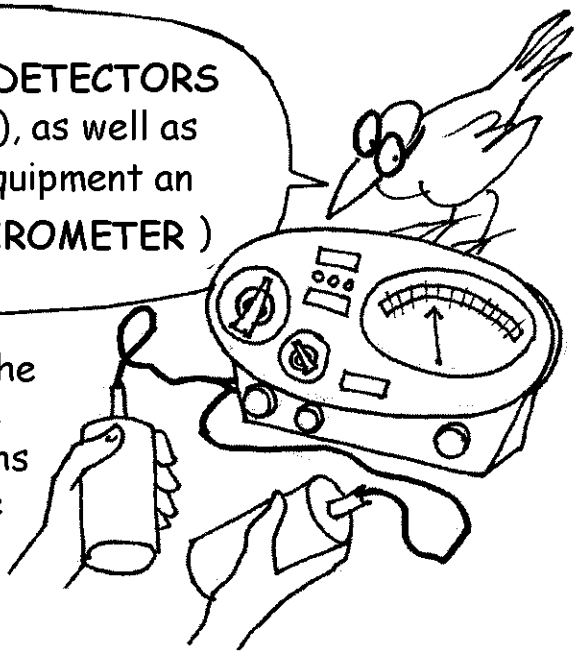
THE DANGERS OF ELECTRICITY



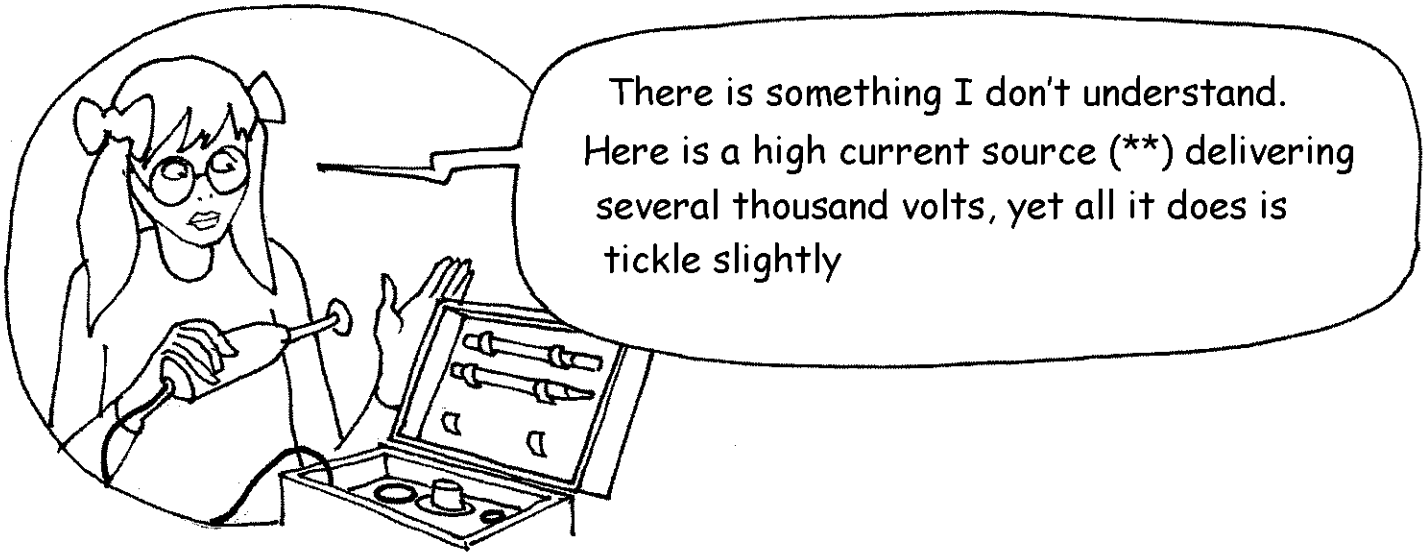




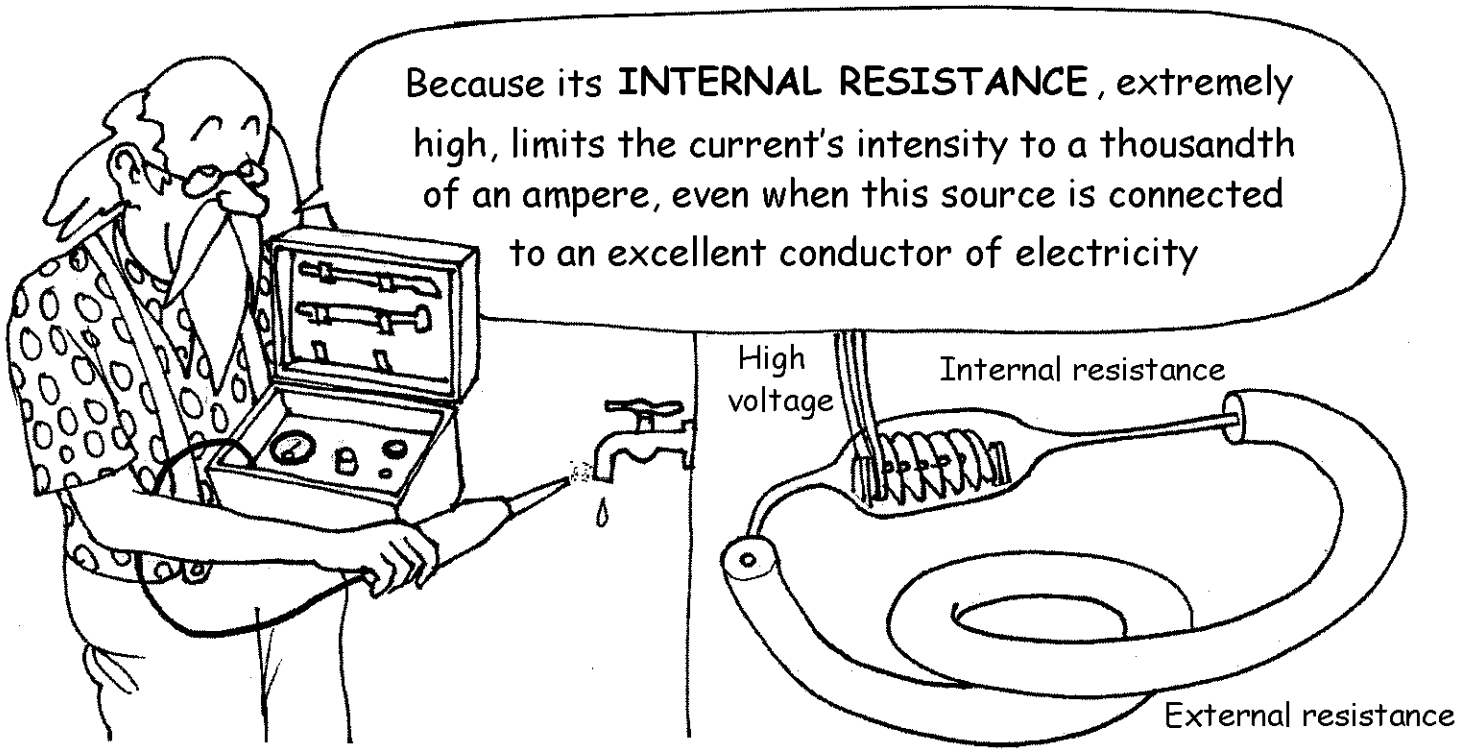
This variation of conductivity is used in **LIE DETECTORS** (people sweat when they lie or are emotional), as well as by the **SCIENTOLOGY** sect, who call this equipment an **ELECTROPSYCHOMETER** (a simple **PERSPIROMETER**)



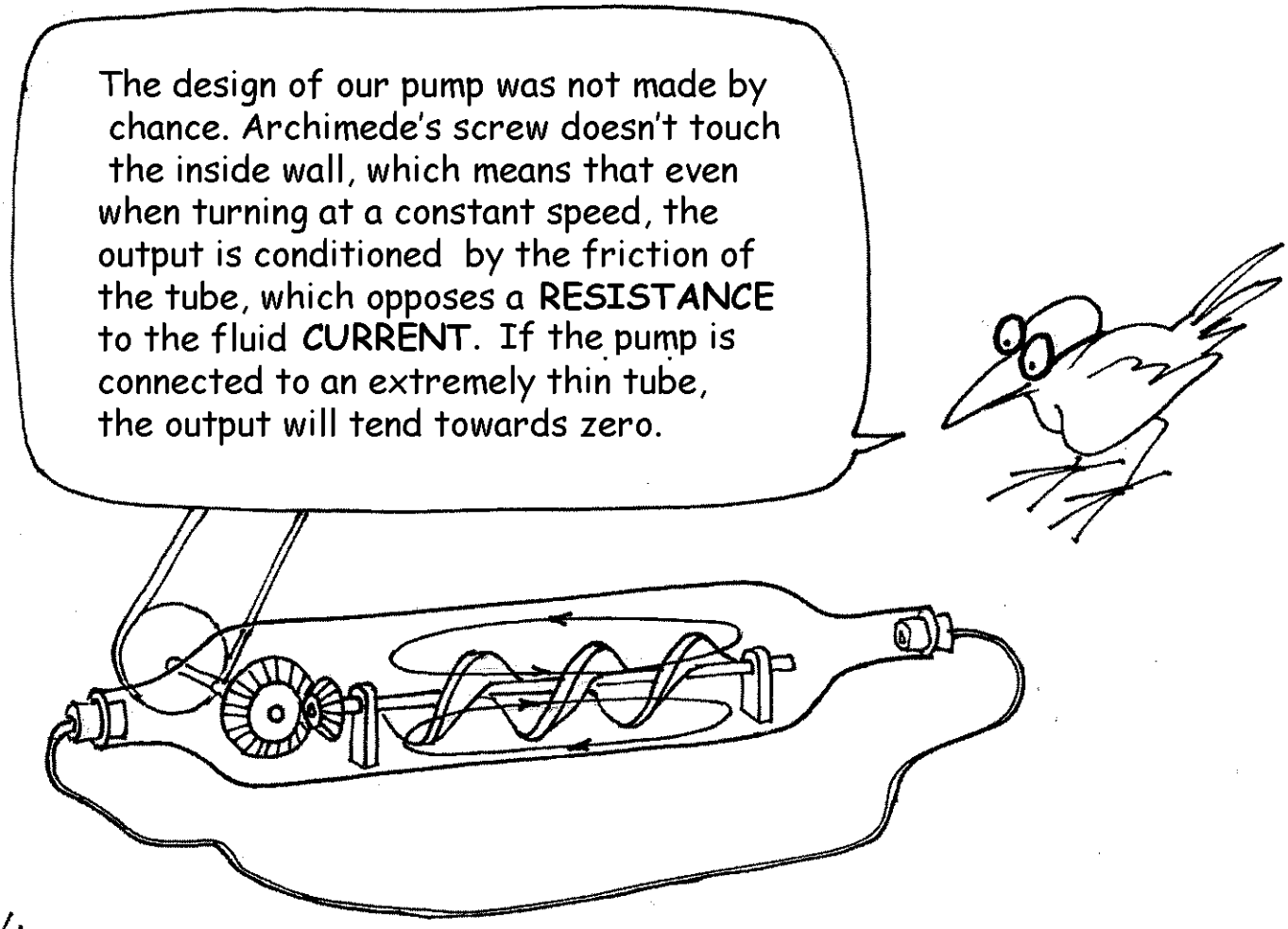
The corporeal damage caused (*) depends on the current's intensity. A thousandth of an ampere creates a slight tickling. With a few hundredths of an ampere, the current takes control of the muscles. Hands remain stuck of the wires, the diaphragm is **TETANISE**, respiration is blocked and this brings about death by asphyxiation. With a tenth of an ampère the heart stops or beats in an incoherent manner (fibrillation).



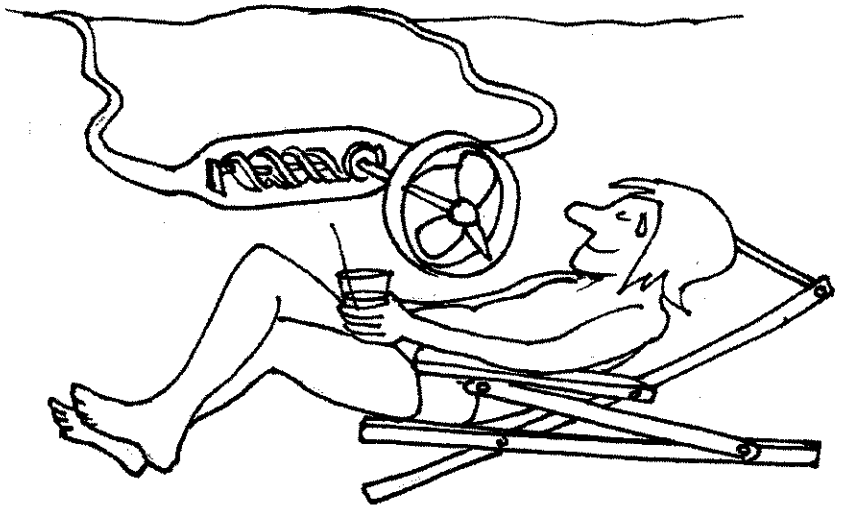
(*) In France, 200 people a year die from electrocution.
(**) a "Rhumkorff coil"



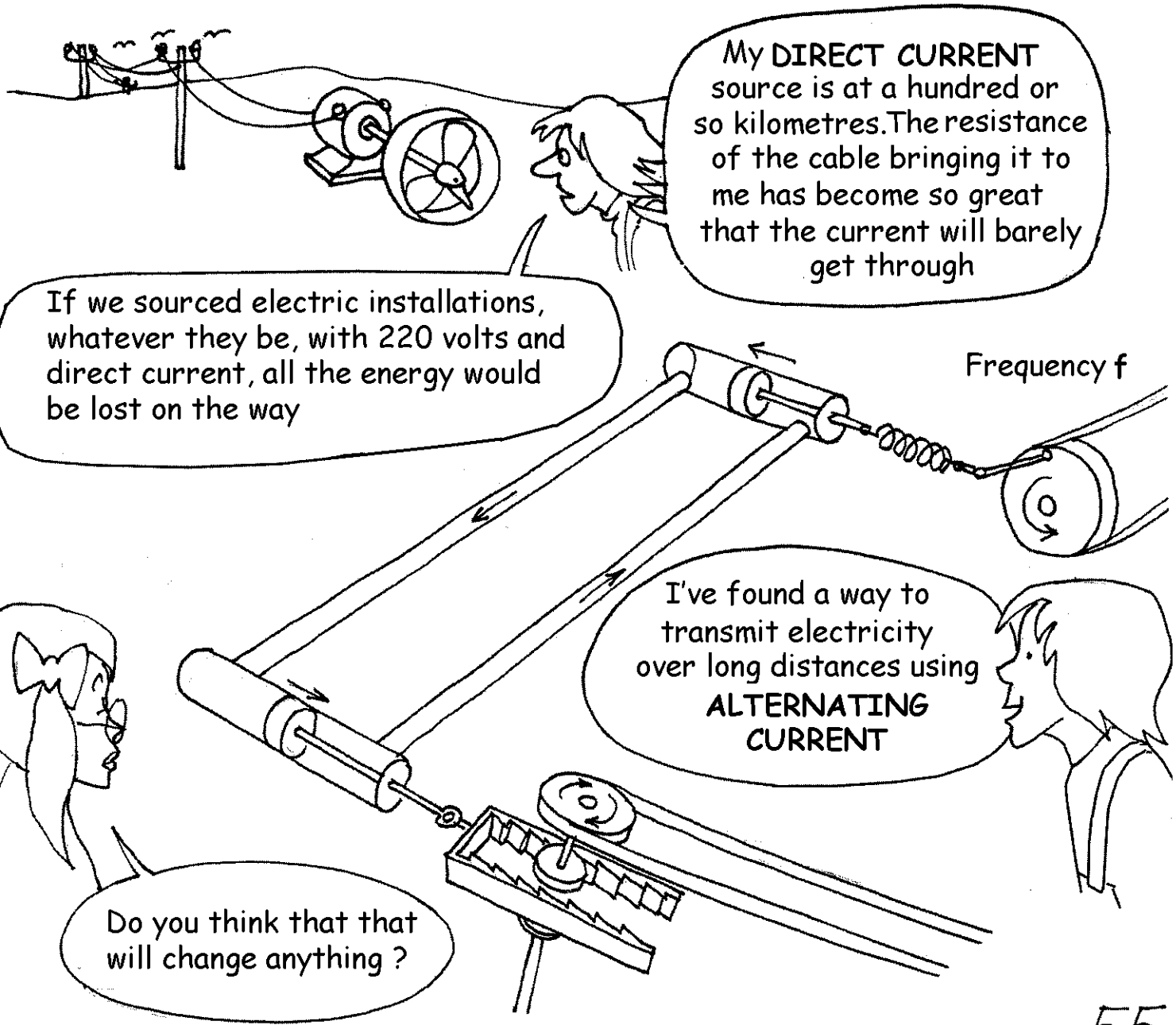
iN LiNE LOSSES

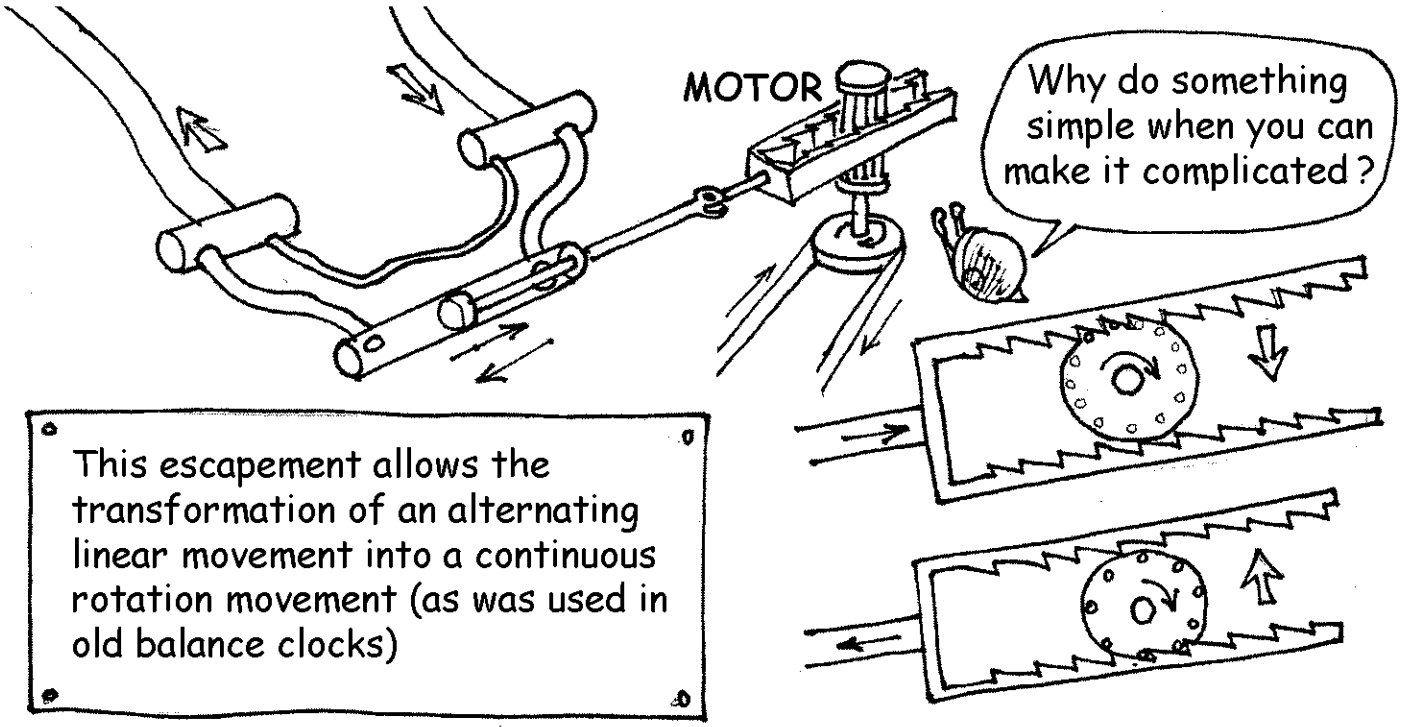


The transport of electricity over long distances ensures many functions. Heating, lighting (by heating an incandescent lamp filament), the production of mechanical energy via **ELECTRIC MOTORS**



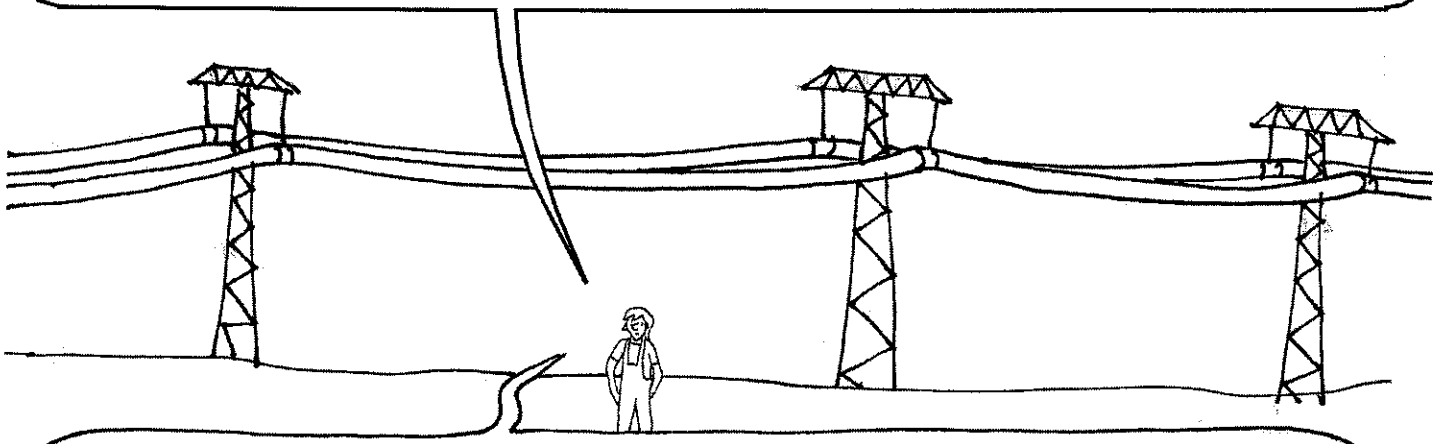
If the conductor bringing it is very long, it will be such a source of friction that the fluid will barely circulate. All the energy will be dissipated in friction and will only serve to heat the environment, it will be lost on the way



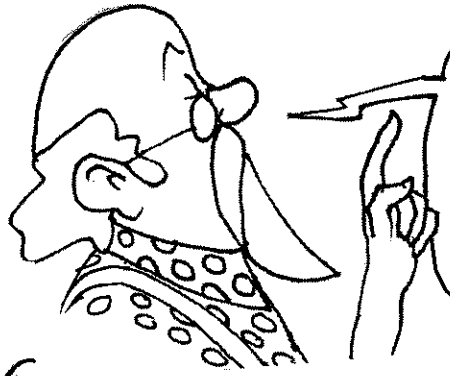


This escapement allows the transformation of an alternating linear movement into a continuous rotation movement (as was used in old balance clocks)

I thought that **ALTERNATIVE CURRENT** allowed easier **ENERGY TRANSPORT OVER DISTANCE**, but even with that, everything is lost on the way because of friction, so in the end I'm just keeping birds warm

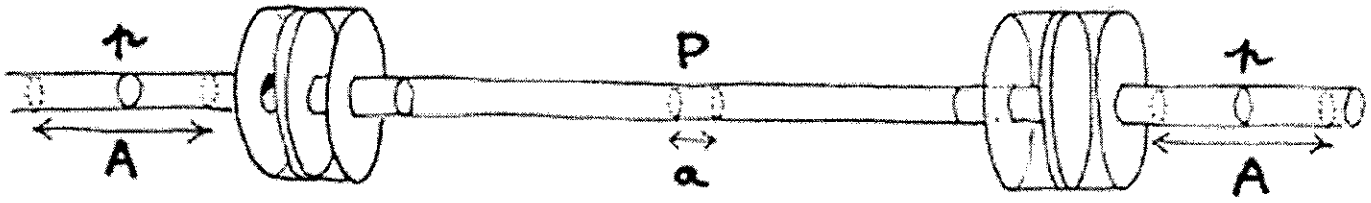


What needs to be done is to reduce the losses due to friction, so the amplitude of the backwards and forwards movement of my fluid, that is to say, at a constant frequency, the output, or in other words, the **INTENSITY**. But then if we reduce this output-intensity, what happens to the **POWER**

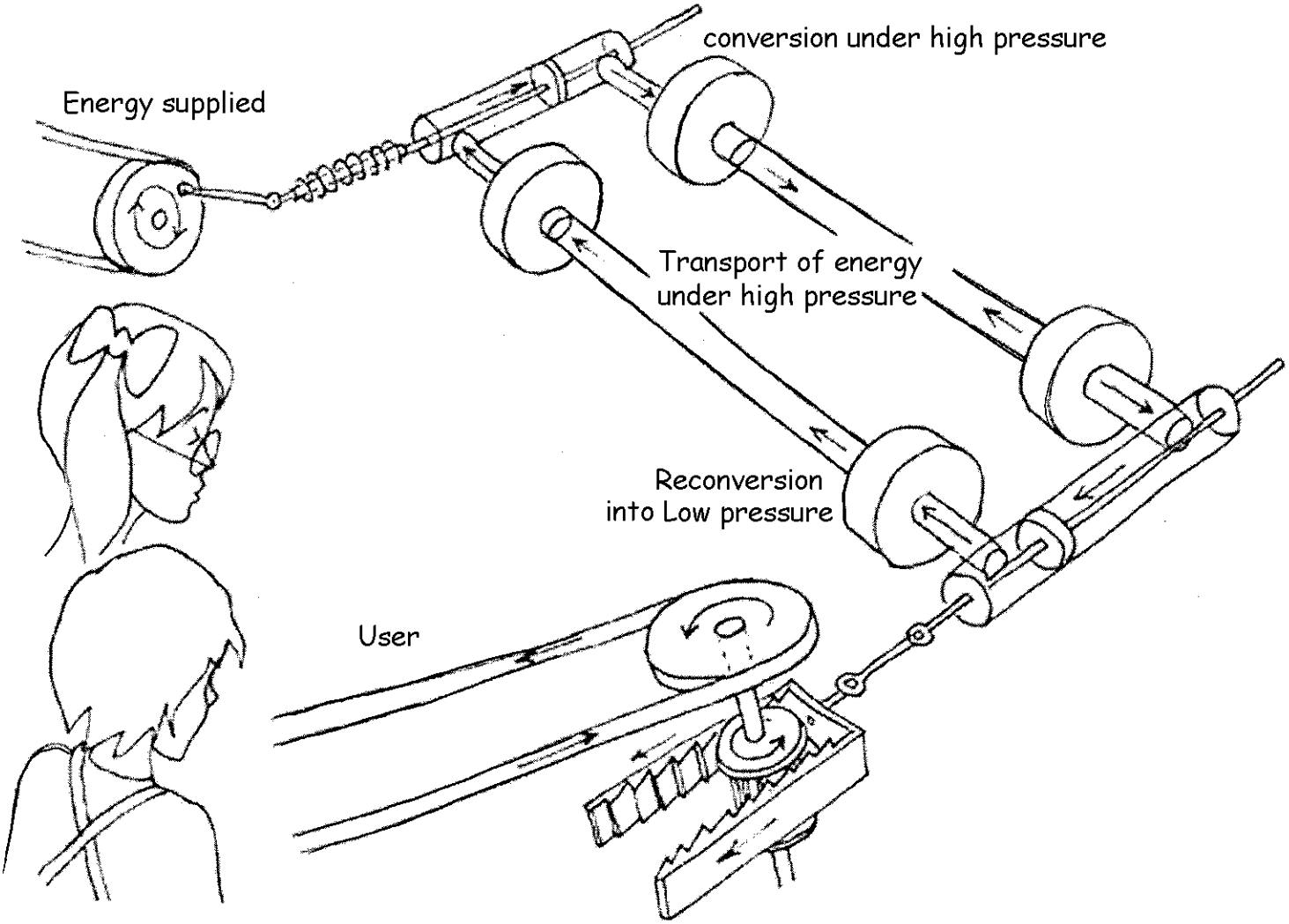


You're forgetting something Archie. Pressure isn't only a force by unit of surface, it's also an **ENERGY DENSITY BY UNIT OF VOLUME** If you reduce the output volume I, by increasing the pressure, you can conserve the energy flow

The solution is the **PLUNGER CYLINDER**, which transforms a large displacement of size **A**, at low pressure **p**, to a small displacement **a**, at high pressure **P**



This formation doesn't change the quantity of energy **p A = P a**, carried at a frequency **f**, but as the fluid displacement is reduced in each cycle, so are the losses due to friction.

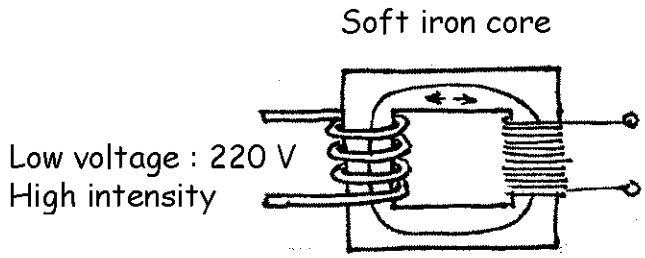


In the world of electricity, the transport of a fluid mass, incompressible, will be replaced by the transport of electric charges. In a conductor carrying an **ALTERNATING CURRENT**, the electric charges have an ebb and flow movement. The word **INTENSITY** replaces the word flow, and the word **VOLTAGE** replaces the word pressure. A **TRANSFORMER** converts the current in such a way that the product **V x I** is conserved. The operating principle, calling on **ELECTROMAGNETISM**, is outside the scope of this album

The Management

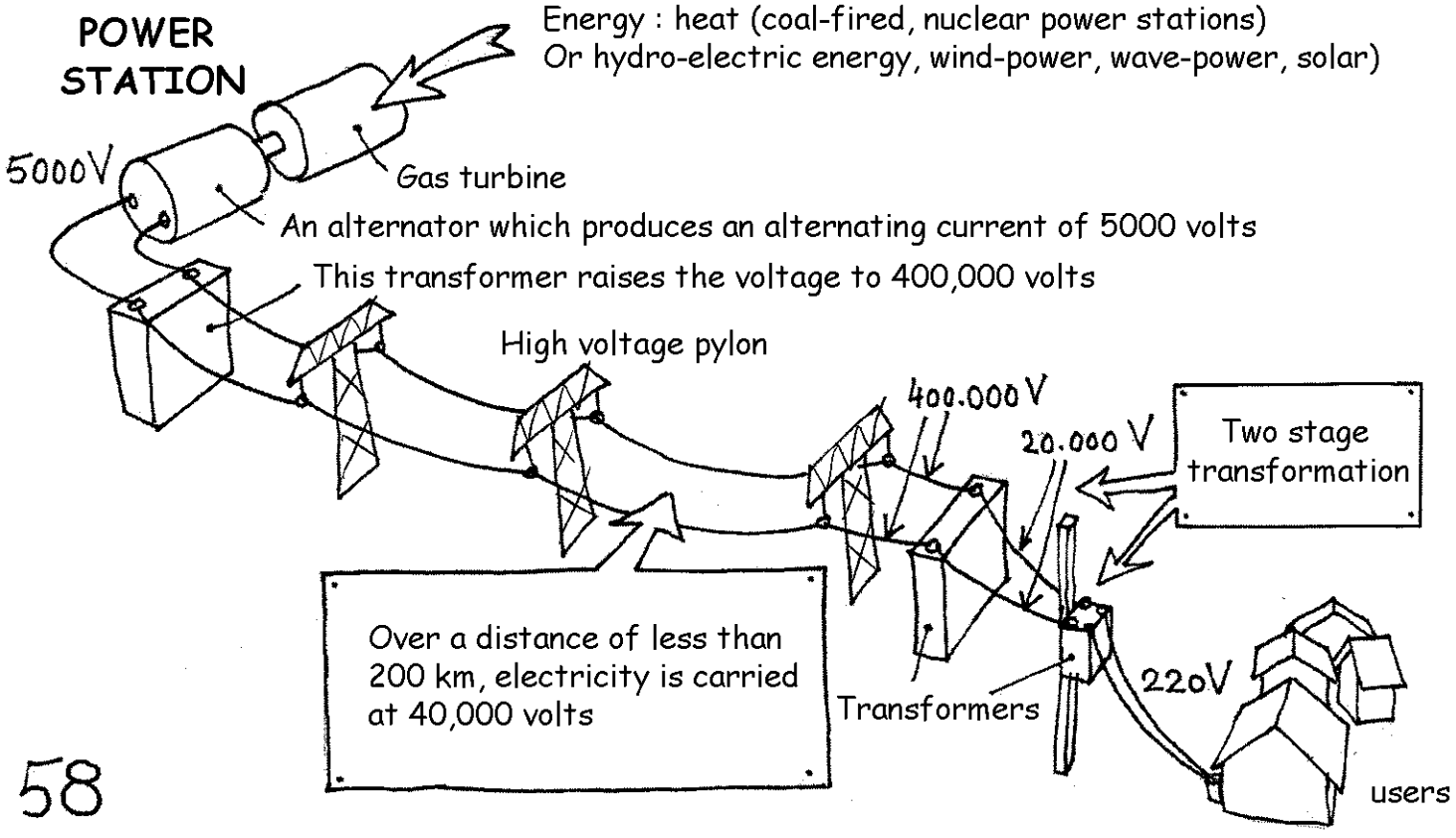
ALTERNATiNG CURRENT AND iTS ViRTUES

Transformers only work with alternating current



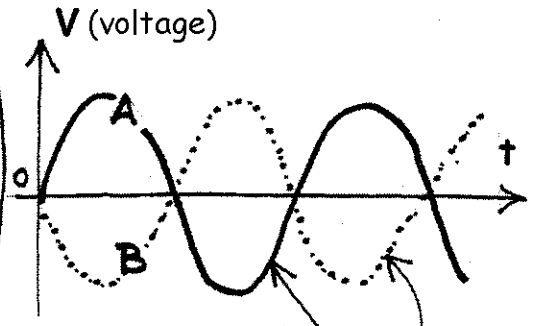
This is what a **TRANSFORMER** looks like.

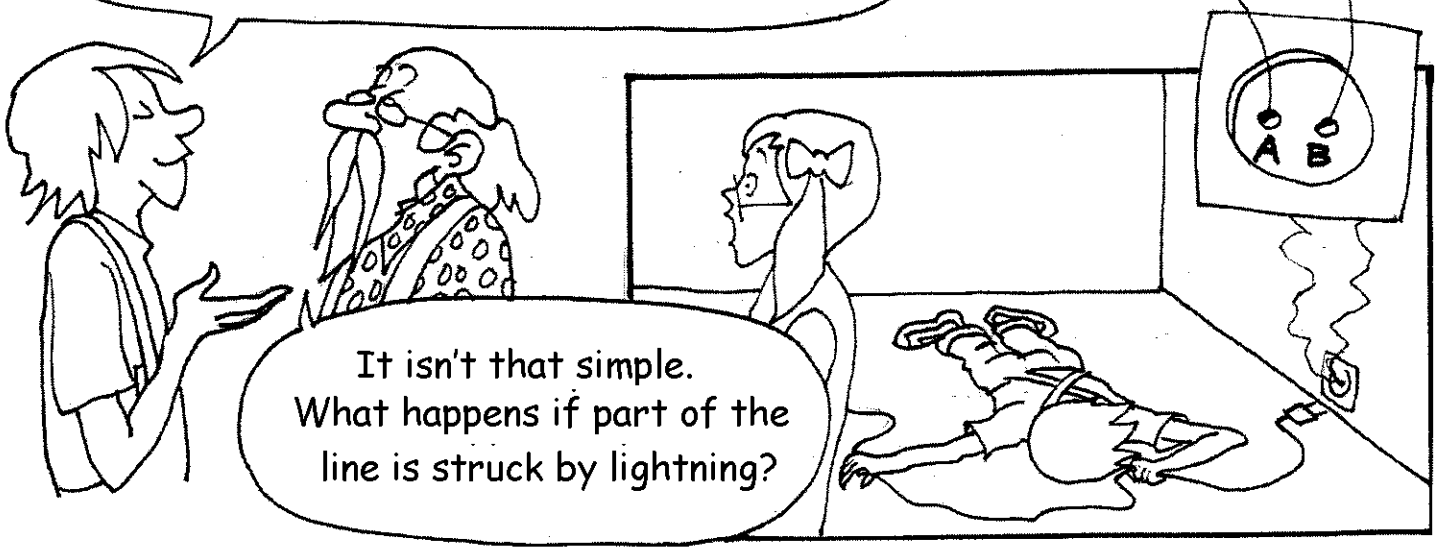
There are two circuits linked by an **ALTERNATING MAGNETIC FIELD** which loops in a **SOFT IRON CORE**. If the power source (called the primary circuit) is on the left and the output on the right (called the secondary), the system functions as a **VOLTAGE INCREASER**, with $V_1 I_1 = V_2 I_2$. If, on the contrary, the source is on the right and the output on the left, it **LOWERS THE VOLTAGE**. This allows the transport of electric power in the form of alternating current in 50 periods (*) at a high voltage (400,000 volts) and an intensity of a few hundred amperes per line, over distances not exceeding 200 km, the **NETWORK** being equipped everywhere with a series of **ELECTRIC POWER STATIONS**



400,000 volt electric lines serve zones and regions. Then 20,000 volt lines feed small towns and areas in large towns. A final stage has transformers the size of washing machines, attached to concrete poles, that feed a dozen houses or their equivalent

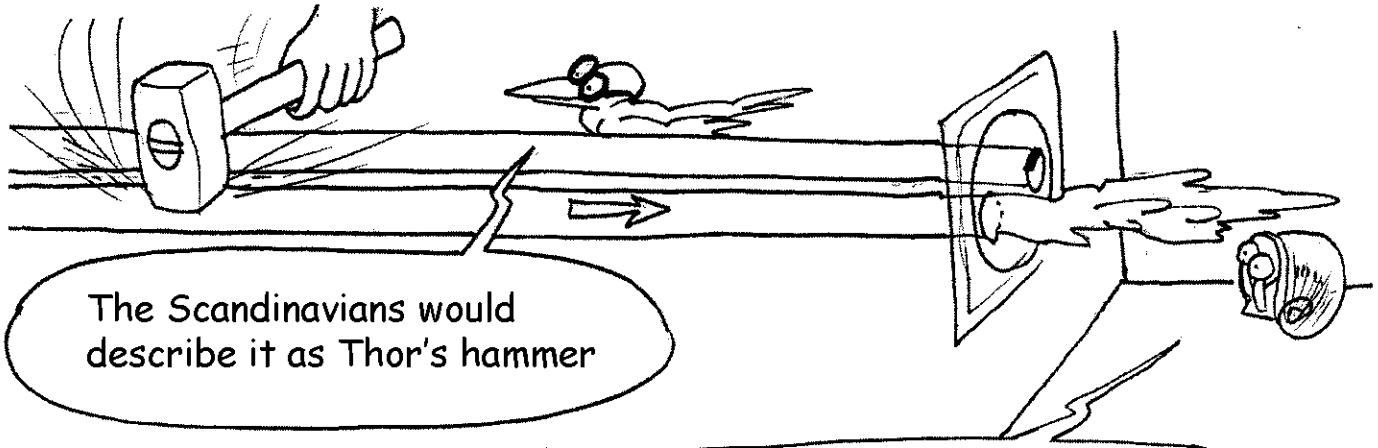
All that seems very simple. You just need to bring two wires, working in opposition, to an electric socket. When one is given a positive voltage, the other has the opposite voltage, and so on, 50 times a second





It isn't that simple. What happens if part of the line is struck by lightning?

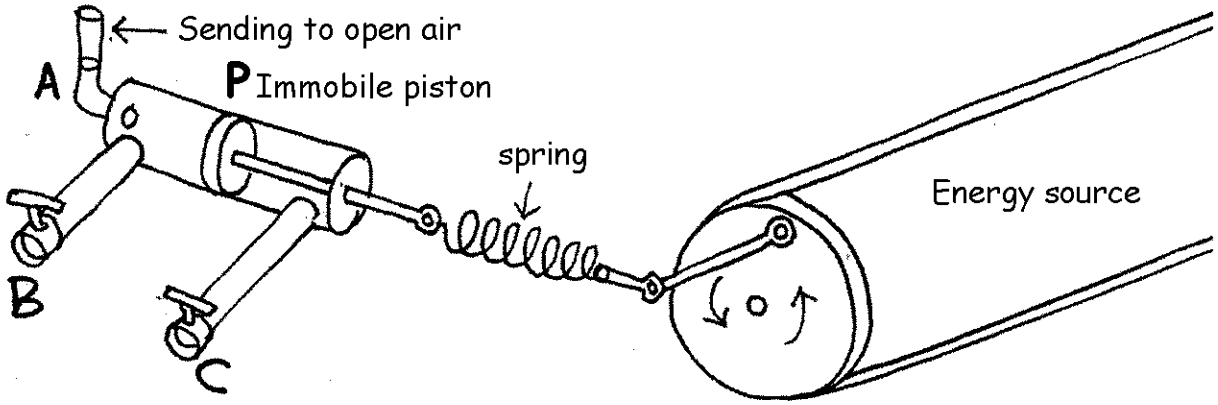
LIGHTNING is something that has to be taken very seriously (*). That isn't a simple laboratory experiment. If we return to the hydraulic analogy, it's the equivalent of an enormous whack with a hammer on a tube carrying liquid : a real ramming.



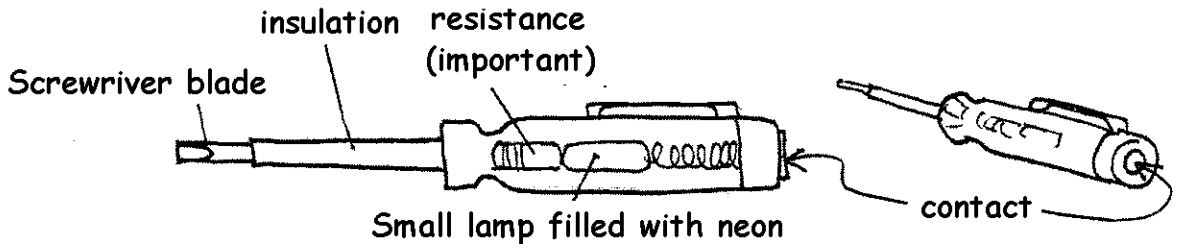
The Scandinavians would describe it as Thor's hammer

Is electric fluid INCOMPRESSIBLE ?

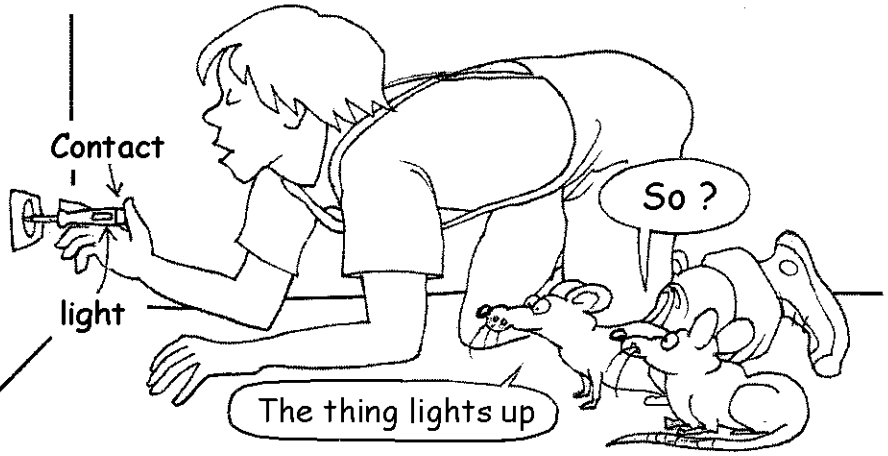
In electricity, what we call the **EARTH** is an immense capacitor into which electric charges can be sent, or taken, without modifying their **VOLTAGE** and to which we give an arbitrary value of zero. In hydraulics, the equivalent is an immense volume, whose **PRESSURE** we can modify. We would take ... the atmosphere. Earthing therefore is **SENDING IT INTO THE OPEN AIR**



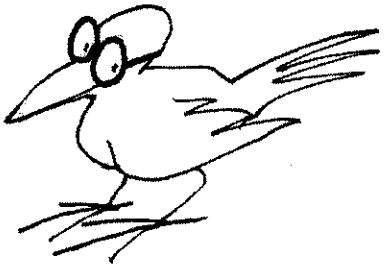
That is the explanation for a mystery that very few people understand. Your electricity sockey is fed by alternating current. When it isn't connected to any electric apparatus, or radiator, a **SCREWDRIVER CIRCUIT TESTER** can be used. You will then discover that only one of the two connections, the **LIVE**, shows a voltage, the other, **NEUTRAL**, does not



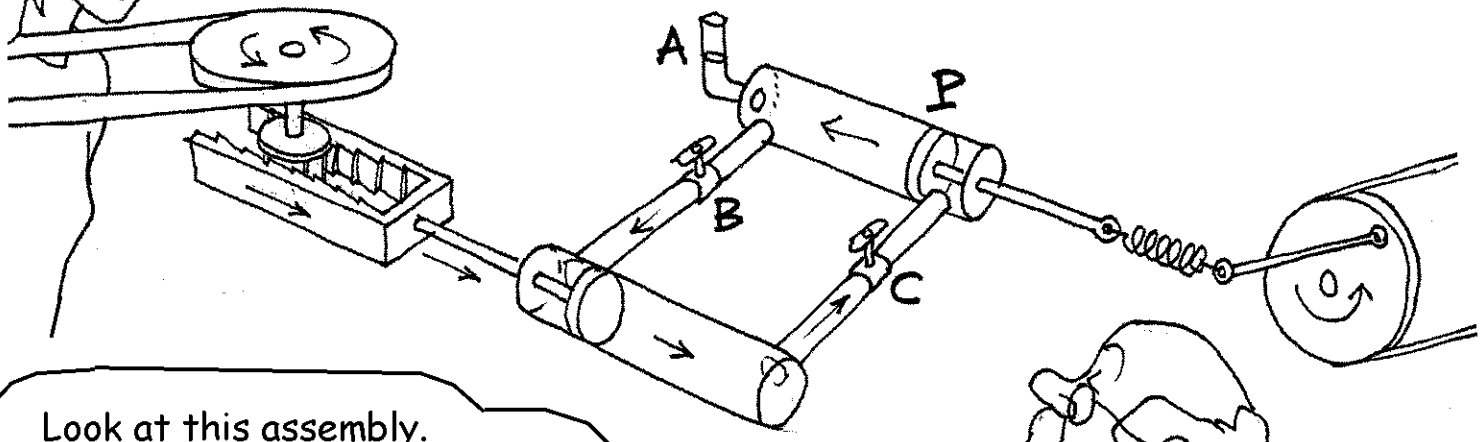
If you look at the circuit diagram above, you can see that the taps **B** and **C** are closed, piston **P** cannot move. Energy is stocked in the spring. Pressure **C** varies, whereas pressure **B** remains nil !



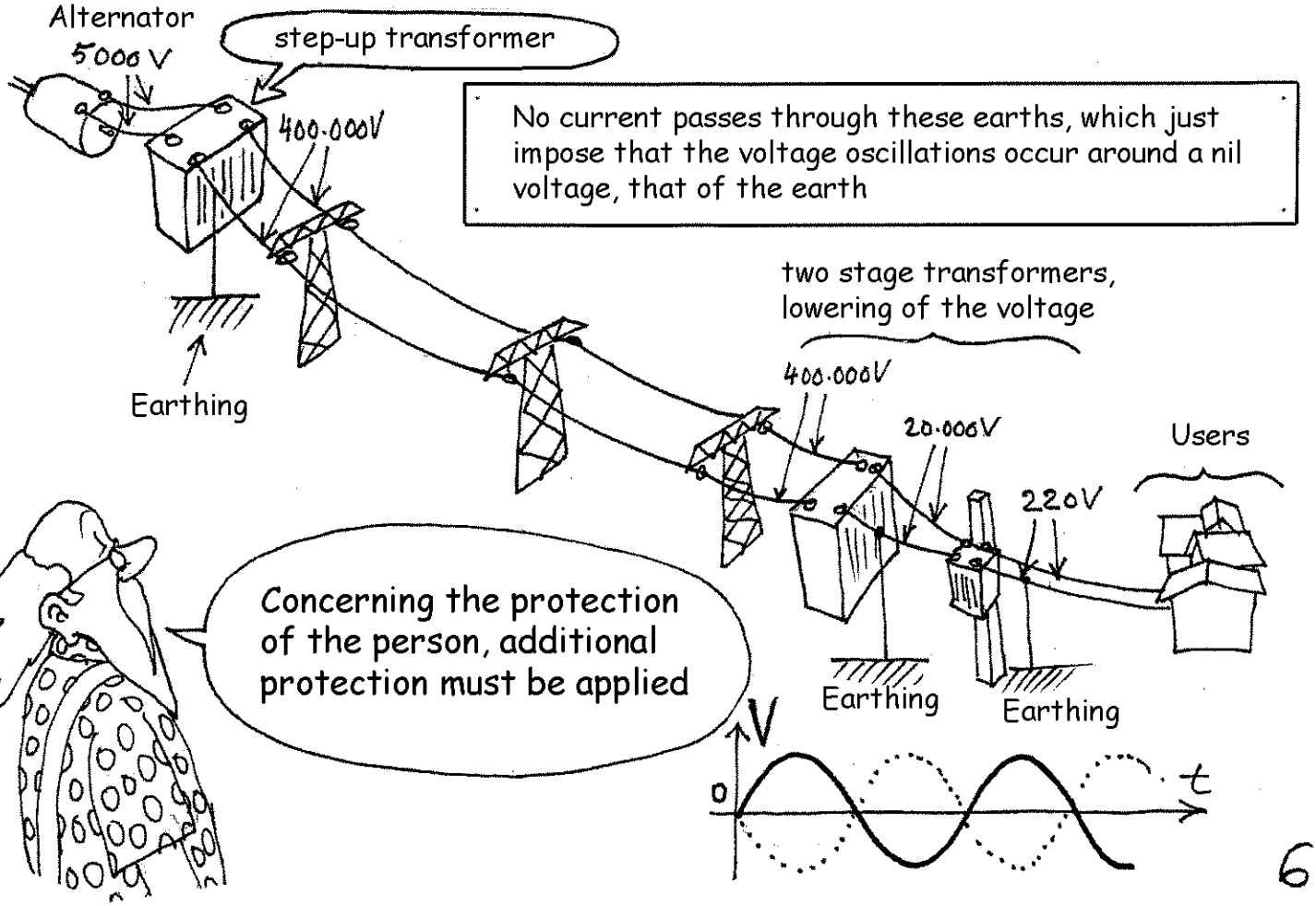
Upstream of your socket, one of the two lines is earthed, which evacuates any overvoltage caused by a lightning strike. Your life depends on this indispensible measure

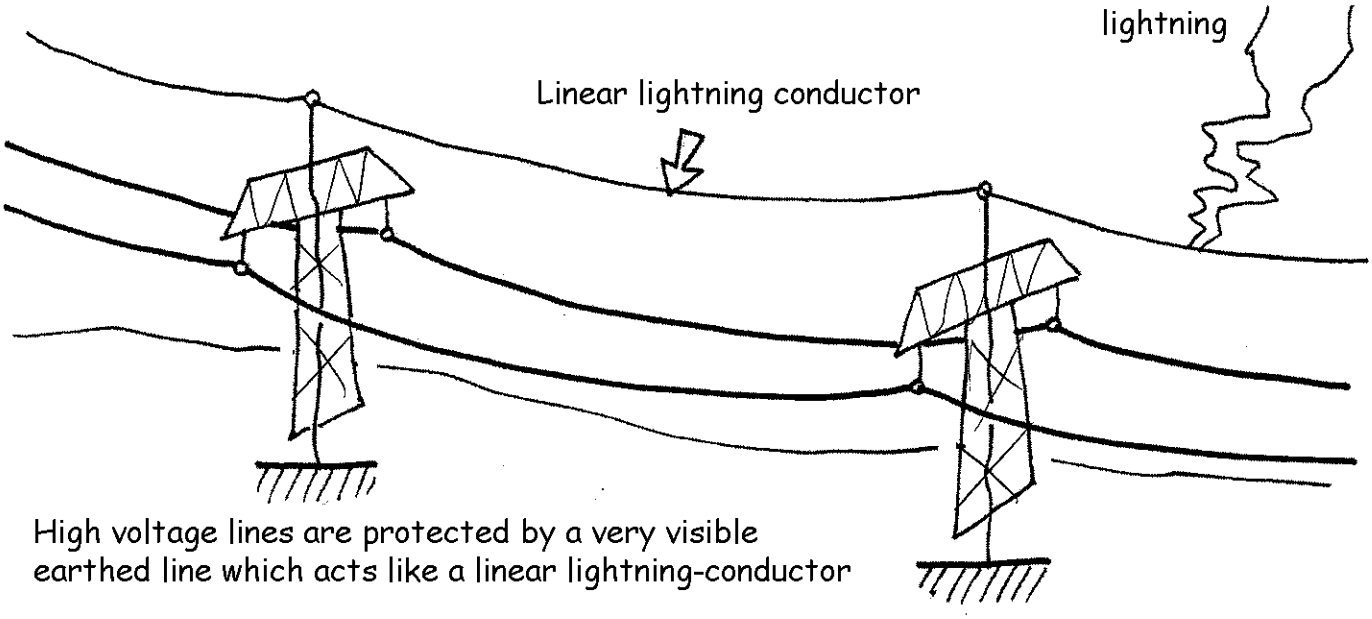


But as soon as something is plugged in, doesn't the current go straight to earth ?



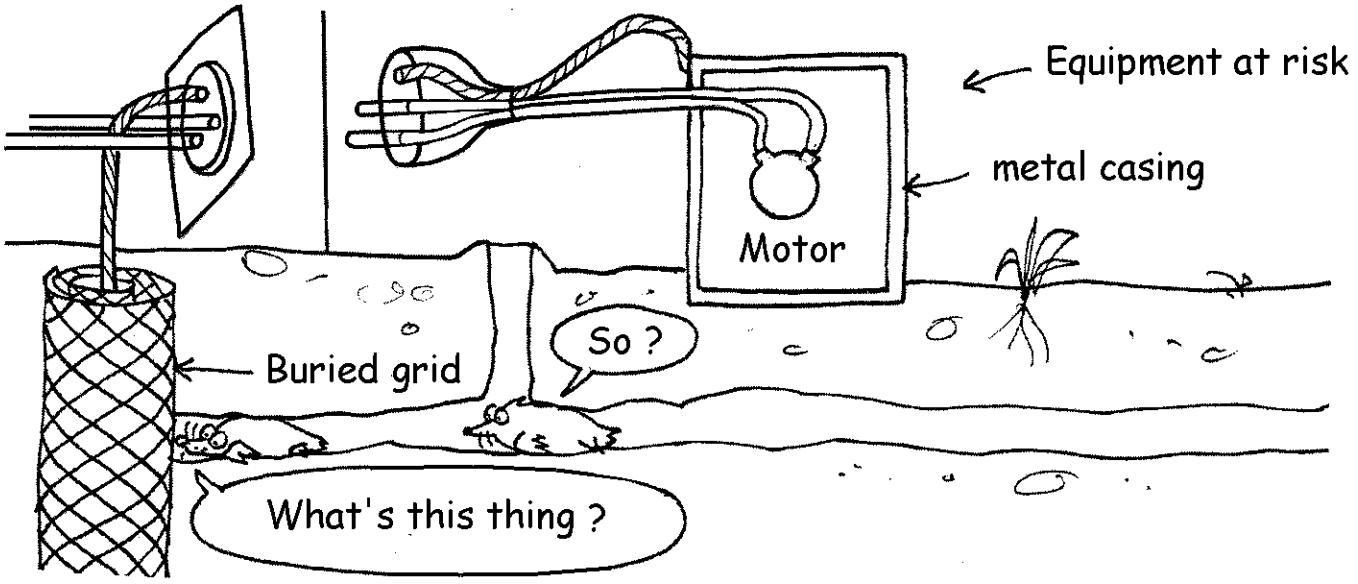
Look at this assembly.
Taps **B** and **C** are open. Piston **P** moves. But the fluid doesn't flow into **A** because it's moving in a closed circuit and is **INCOMPRESSIBLE**. If a fluid volume flows into **A**, where does it come from? In this case the pressures in **B** and **C** vary, but the assembly is such that the pressure variations can only remain around that of the atmospheric pressure value, whether it be a question of low or high pressure. In transporting electricity, this earthing means that the fluctuations of low and high voltage can only operate around a nil voltage

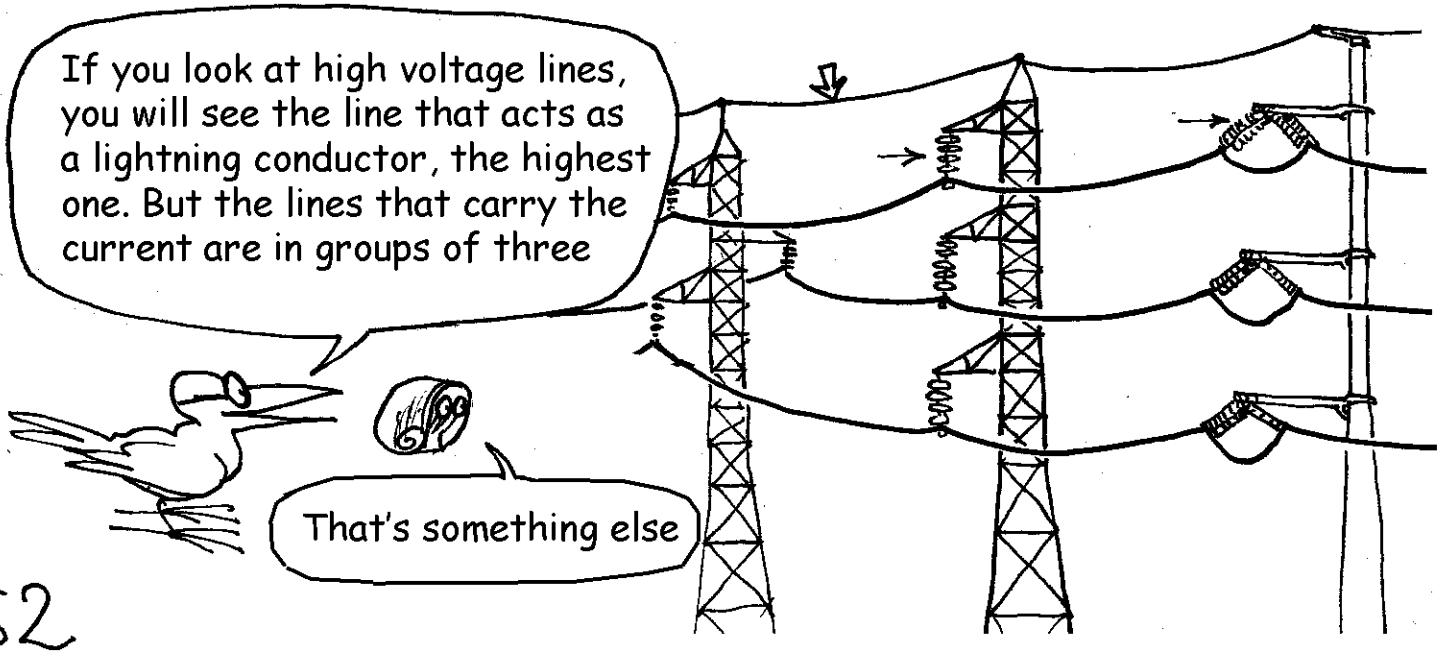


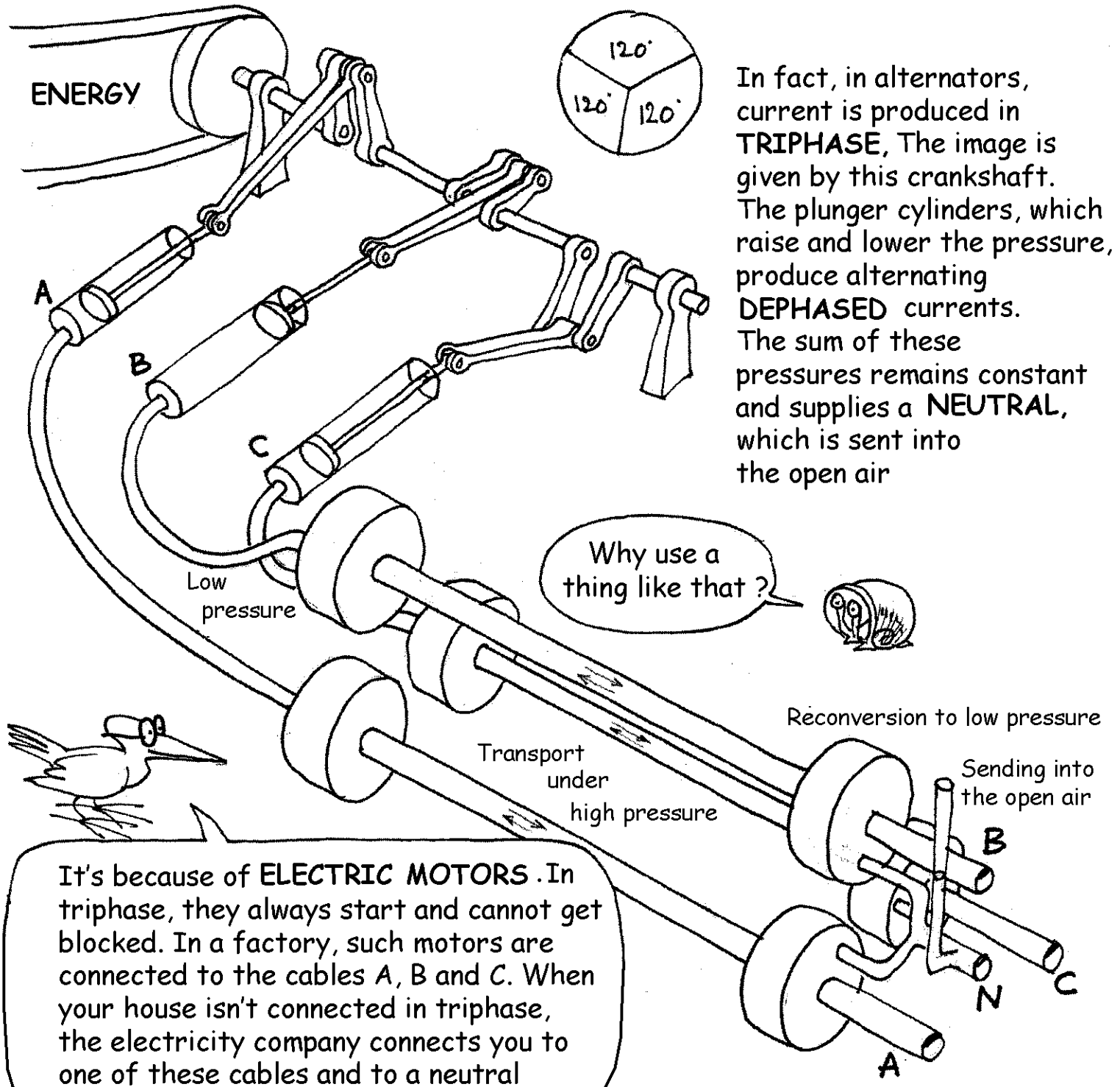


High voltage lines are protected by a very visible earthed line which acts like a linear lightning-conductor

Earths are therefore multiplied. In users' homes there is another earth, that of the house, which is connected to all the equipment "at risk"







In fact, in alternators, current is produced in **TRIPHASE**, The image is given by this crankshaft. The plunger cylinders, which raise and lower the pressure, produce alternating **DEPHASED** currents. The sum of these pressures remains constant and supplies a **NEUTRAL**, which is sent into the open air

It's because of **ELECTRIC MOTORS**. In triphase, they always start and cannot get blocked. In a factory, such motors are connected to the cables A, B and C. When your house isn't connected in triphase, the electricity company connects you to one of these cables and to a neutral

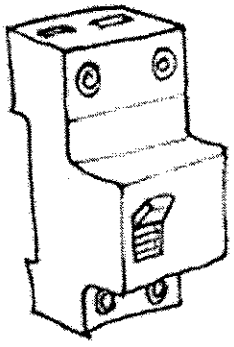
So if you've followed all that, you belong to a rare group of privileged people who understand what **TRIPHASE** is

EPiLOGUE

So now we know a little more about ELECTRICITY

With this test screwdriver we can find out if an object is receiving a current

We have learnt that electric equipment shouldn't be touched with wet hands, or when your feet are in water



To be complete, we'll finish by mentioning the DIFFERENTIAL CIRCUIT BREAKER. This is an electromagnetic apparatus that controls the absolute values that pass through the live and neutral when an installation is being supplied with electricity. If the apparatus detects a difference of 10 to 20 milliamperes, it means that there is a current leak somewhere so the circuit-breaker automatically cuts the current off

Many thanks to my old friend
Jacques Legalland without whose help
I would not have been able to finish
this album

END